19th conference of the European chapter
of the Society of Wetland Scientists

Wetlands across timescales

Book of Abstract

JUNE 24-26th 2024, GONIĄDZ, POLAND

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Organised by Society of Wetland Scientists, Europe Chapter & Wetlands Conservation Centre (PL), University of Warsaw, Białystok University of Technology, Warsaw University of Life Sciences, Society for the Protection of Habitats “ProHabitat” & The Biebrza National Park.

Sunday (23 June)	
20:00-21:00	**Registration and welcome reception (Hotel)**

Monday (24 June)		
8:00 – 9:00	**Registration (Hotel)**	
9:00-10:45	**OPENING PLENARY SESSION: WETLANDS ACROSS TIME SCALES** (chair Wiktor Kotowski) **(lecture room A)**	
09:00	**Opening addresses**	
09:10	**Keynote lecture - Jane Madgwick:** Wetlands as essential global commons	
09:50	**Keynote lecture - Mariusz Lamentowicz:** Wetlands across time: exploring, understanding, and predicting their development and functions at local and global scales	
10:30	**Łukasz Kozub:** Introduction mid-conference field trips	
10:45-11:15	**Coffee break**	
PARALLEL SESSIONS		
11:15-13:00	**I – LEARNING FROM THE PAST** - chair Mariusz Lamentowicz **(lecture room A)**	**II – THE RACE AGAINST POLLUTION** - chair Dominik Zak **(lecture room B)**
11:15	**Jakub Niebieszczański**: Island, lake and wetland: a palaeoecological and geoarchaeological reconstruction of Early Bronze Age and Early Iron Age settlements in Bruszczewo (Western Poland)	**Jan Vymazal**: Ecosystem Services of Urban Wetlands
11:30	**Karina Apolinarska**: The temporal variability of the Holocene $CaCO_3$ deposition at four alkaline fens in the young glacial area of central Europe	**Adam Sochacki**: Subsurface flow constructed wetlands for the treatment of agricultural drainage: over five years of operation
11:45	**Sambor Czerwiński**: How paleoenvironmental data obtained from peatlands (and lakes) can fill the gap in archaeological and historical sources	**Renske Vroom**: Floating ferns for wetland restoration? Lessons learnt from four years of Azolla cultivation on former agricultural soils
12:00	**Eliise Kara**: Holocene wetness and growing season changes in Linje mire, Poland	**Niels van Putte**: Historical soil compaction impairs biogeochemical cycling in restored tidal marshes through reduced groundwater dynamics
12:15	**Harry Roberts**: Exploring the effects of human activity and fire on vegetation, hydrology and carbon accumulation in Mustjärve, Northwest Estonia	**Andrew S. Wolff**: Characterizing the Beneficial Uses of Arcata Marsh Constructed Wetland System and Wildlife Sanctuary
12:30	Magdalena Suchora[b]: Wetlands of Western Polesie (E Poland) under the human impact – palaeolimnological perspective	**Stefan Lorenz**: Simultaneous pesticide dynamics in surface water and subsurface shallow groundwater in depressional wetlands of north-east Germany
12:45	**Mar Albert-Saiz**: The importance of water table depth thresholds in peatlands' restoration	**Luca Marazzi**: A Citizen Science and Engagement Approach to Tackle Plastic Pollution in England
13:00-14:00	**LUNCH**	

Monday (24 June)		
PARALLEL SESSIONS		
	III – RESTORATION: TRADE-OFFS AND LEGACIES OF THE PAST - chair Christian Fritz **(lecture room A)**	**IV – FLOW WITH THE WATER: HYDROLOGY AND MONITORING** - chair Ilona Biedroń **(lecture room B)**
14:00	**Gerald Jurasinski**: Bright spots of peatland rewetting	**Maria Grodzka-Łukaszewska**: Quantification the Mowing and Draining Debate using a model of the Biebrza Wetlands
14:15	**Tom Heuts**: Rewetting without land-use change: Have your peat and eat it too	**Floris Keizer**: Revisiting the Flood Pulse Concept – Hydrological processes steering spatial floodplain zonation
14:30	**Sannimari Käärmelahti**: Effects of different irrigation techniques on *Sphagnum* growth and nutrient dynamics in Sphagnum paludiculture	**Goedele Verreydt**: Updating an Upper Biebrza Valley model based on unique real-time measurement of groundwater fluxes
14:45	**Wiktor Kotowski**: Learning to think like the landscape. How to avoid trade-offs and maximize synergies in wetland restoration.	**Martyna Wietecha**: How to assess peatland drying using remote sensing?
15:00	**Michael Manton**: Time for a change in peatland forest management: rewetting delivers €100 billion more than wood production	**Julian Rudziński**: Change in Wetland Management over Time – Karolinów village in the Kampinos National Park
15:15	**Dominik Henrik Zak**: Better Slow than Fast: another Rewetting Strategy	**Nik Ojdanič**: The importance of environmental variables on yearly changes of reed stands – a data mining approach
15:30	**Carl Christian Hoffmann**: Raising the water level by simple ditch blocking did not improve nutrient retention in a fen	**Igor Zelnik**: Numerous gradients shape diverse wetland plant communities on intermittent Lake Cerknica
15:45	**Christian Fritz:** Paludiculture – future wetland generation from degraded peatlands	**Marija Chobanova:** Wetland area assessment in North Macedonia
16:00-17:00	**Poster session and drinks – chair Piotr Banaszuk (lecture room A)**	
17:00-18:00	**SWS technical meeting** **(lecture room B)**	**Walk to the floodplains of Biebrza (optional)**
19:00-20:00	**Dinner**	
20:00-22:00	**Students get-together (lecture room B)**	

	Tuesday, 25 June
9:00-17:00	**Field trips by bus (parking in front of the hotel)**
17:30-20:00	**Dinner and aperitif (Restaurant)**
20:15-22:20	**SPECIAL PLENARY SESSION: (lecture room A)** **FOUR DECADES ON DUTCH-POLISH RESEARCH COLLABORATION IN BIEBRZA WETLANDS** (chair Tomasz Okruszko)
	Laudation by Artur Wiatr, director of Biebrza National Park
	Keynote lecture - Martin Wassen: Thank you Biebrza!
	Panel discussion "Biebrza for science – science for Biebrza" (chaired by Tomasz Okruszko)
22:20-24:00	**Banquet at the Biebrza River bank**

PLENARY TALKS

Wednesday, 26 June		
	PARALLEL SESSIONS	
	V – PEATLAND ECOLOGY IN A CHANGING WORLD - chair Rudy van Diggelen **(lecture room A)**	**VI – INTO THE FUTURE: PREDICTING AND PLANNING** - chair Magdalena Suchora **(lecture room B)**
09:00	**Michal Antala:** The photosynthetic capacity of bog cranberry (Vaccinium oxycoccos L.) and sphagnum moss (Sphagnum spp.) increases with warmer late winter and early spring: A climate manipulation study	**Robert McInnes:** Setting the global agenda for wetlands: The past and future of strategic planning for the Convention on Wetlands
09:15	**Keith Edwards:** Multiple environmental factors interact to affect wet grassland CO2 and CH4 emissions	**Christopher Craft:** Tidal Forest Productivity and Biodiversity: A Southeastern U.S. perspective
09:30	**Jan Kucharzyk:** Notes on ecological factors shaping vegetation diversity of mires in Norwegian Finmark	**Michał Nowak:** Predicted effects of climate change on native and alien fishes in a large floodplain river (Middle Vistula River, Poland)
09:45	**Andrzej Kamocki:** Implementation of the Nature Restoration Law more needed than ever: A case study from the most pristine (?) riverine wetlands in Poland.	**Przemysław Nawrocki**: High resolution assessment of the state of river hydromorphology in Poland: legacy of the past, challenges for now and for the future
10:00	**Nina Trochanowska:** Exploring the Impacts of Tree Encroachment and Mowing on Fungal Communities in Fens	**Ilona Biedroń:** Restoration of rivers in Poland. Experiences and challenges.
10:15	**Remco Versluijs:** How changed river dynamics affected flow patterns in the percolation rich fen of the Rospuda Valley, NE-Poland.	**Mathais Scholz:** Land requirements for floodplain development and restoration in Europe
10:30	**Izabela Jaszczuk:** Stability is the key – the peat formation potential of fens increases with decreasing water level fluctuations	**Matthew Simpson:** Transformative change for wetlands: learning the lessons from communities to governments
10:30-11:00	**Coffe break**	
11:00-12:30	**CLOSING PLENARY SESSION: TIME TO RESTORE** **(lecture room A)** - chair Matthew Simpson	
11:00-11:40	**Keynote lecture - Rudy van Diggelen:** Time to restore. What can science do to bring power to the peatlands?	
11:40-12:20	**Keynote lecture - Viktar Fenchuk:** Wetland restoration in the National park “Bielaviežskaja pušča” – the Belarusian part of the Bialowieza forest. Summary of the two decades of work	
12:20-12:30	**Students award announcement**	
12:20-13:00	**General discussion and closing ceremony**	
13:00-14:00	**Lunch**	
14:00	**Departure by bus to Warsaw**	

SOCIETY of WETLAND SCIENTISTS
Europe Chapter

PLENARY TALKS

Wetlands as essential global commons

Jane Madgwick

Executive Director, Global Commons Alliance

My presentation will introduce the interactions between human use, culture and wetlands over time and look to the future needs and prospects. Using wetland examples from around the world, I will illustrate how understanding the dynamics of wetlands over time and space, have been important to design ongoing conservation and restoration initiatives, mentioning some dilemmas and gaps to be resolved. I will consider the growing case to bring focus on safeguarding wetlands as “global commons”, a critical means to bring planetary resilience in the context of the Anthropocene. I will introduce how Earth system science is developing to drive action for a safe and just future and invite discussion on how this can be brought to the ground at different scales.

Jane Madgwick

Ecologist and author with 30 years of experience of working internationally on natural resource management, with a special focus on water and wetlands. She became the first Executive Director of the Global Commons Alliance in May 2023. Previously Jane worked for Wetlands International, as well as WWF in Europe and Australia. As CEO of Wetlands International for almost 20 years, she enabled multi-stakeholder coalitions conserve and restore wetland landscapes for biodiversity, human well-being and reduced climate risks and to bring the values of wetlands into the global agenda. Jane is committed to enable urgent action for an environmentally safe and socially just future.

PLENARY TALKS

Wetlands across time: exploring, understanding, and predicting their development and functions at the local and global scales

Mariusz Lamentowicz

Climate Change Ecology Research Unit, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University, Poznań, POLAND

EARLY WETLANDS

Wetlands' history on Earth is highly complex and still not sufficiently explored. Their earliest origins are poorly understood, resulting in a scarcity of reliable geological records accessible for appropriate interpretation. However, available data allow us to determine the appearance of wetlands' beginnings and peat-forming conditions. The story starts with stromatolite (cyanobacteria) mounds, the oldest fossil life on Earth, dating to over 2 billion years. However, the origin of wetlands was directly related to the appearance and evolution of vascular plants and mosses and their adaptation to thrive in wet conditions ca 420 Ma (Greb et al., 2006). The oldest marshes were identified in Middle Devonian (Eifelian) 410 Ma, and the continuous peat appeared in Late Devonian 370 Ma. The onset of the first peatlands on Earth is a fascinating step into terrestrial wetland conditions, and it relates to new plant function in the peatland ecosystem as it begins the carbon accumulation process on a global scale. The initial peat arrived in the middle-late Devonian; however, peat accumulation on the full scale began in the late Devonian–Carboniferous 350-360 Ma. Different wetlands were identified at that time, resembling coastal marshes or mangroves (Greb et al., 2022).

CARBONIFEROUS

The Carboniferous starting ca 360 Ma was the period of peatlands, where new ecosystems emerged together, shaping new biodiversity. N America and Europe were covered with peatlands during the "Coal Age" (Thomas, 2012). Peat-forming wetlands were affecting the climate by removing CO2 and storing it for the next millions of years. Simultaneously, other wetland types, such as lakes and rivers, have developed globally. Peat accumulation stopped for millions of years with the Permian extinction (ca. 250 Ma), with no peatlands/coal known anywhere until the Middle Triassic (243 Ma) (Retallack et al., 1996; Thomas, 2012). Then, it started again later in the Mesozoic period when peatlands and other freshwater wetlands were redeveloped. Despite the global extinction, billions of tons of carbon are stored in the geological strata. Mosses also formed Carboniferous peatlands, but their fossils are rarely found (Hübers and Kerp, 2012). Phylogenetic analyses tell that Bryophyta (mosses) diverged from other land plants before the vascular plants diversified during the mid-to-late-Paleozoic (Shaw and Renzaglia, 2004).

CENOZOIC

Wetlands in the Cenozoic starting 66 Ma became more diverse while vascular plants adapted to the salty water, and a new taxon/engineer evolved - *Sphagnum*, diversified in Miocene which started constructing new acid peatlands just about 14 mya, coinciding with the end of the mid-Miocene climatic optimum and the appearance of peatland ecosystems in the northern boreal zone (Shaw et al., 2010). Miocene peatlands provided thick deposits of lignites (Widera, 2021). Earth wetlands history occurred in the complex geological scene of the moving continents and evolutionary processes stopped by extinctions. It led to many adaptations and various taxa that cannot be recognized today. The palaeoecology of wetlands possesses many gaps, one of which is the underrepresentation of non-peat-forming wetlands in contrast to well-preserved coal strata. Another problem is the limited information about the past biodiversity, including functional traits and evolutionary aspects of organisms constructing wetland ecosystems.

PLENARY TALKS

However, it is intriguing how well plants adapted to peat accumulation through growth in optimally inundated conditions and effective accumulation of thick peat deposits.

QUATERNARY

After over 470 My of evolution, the Quaternary (starting 2,58 Ma) marked the time of the modern wetland, which existed in pulses of glacial-interglacial cycles. While time, climate, geology, and astronomic drivers were shaping them in deep time, the Quaternary provided another evolutionary product that started changing wetlands on a global scale — humans. Wetlands were destroyed and then regenerated by ice sheet expansions. In the Quaternary *Sphagnum* peatlands started to dominate in the N hemisphere peatlands. Then, 12,000 years ago, when humans started to change landscapes, wetland functions began to be modified due to deforestation and the neolithic agrarian revolution (Ellis, 2021; Ellis et al., 2021). The Holocene wetlands have been crossing tipping points related to global warming, drainage and exploitation (Fluet-Chouinard et al., 2023; Treat et al., 2024}. For example, high-resolution multi-proxy studies showed that in Europe, the most intensive changes in wetland ecosystems started in Medieval times (ca 700 yrs BP) and were initially related to deforestations that accelerated lake terrestrialization and lake-to-peatland transitions (Karpińska-Kołaczek et al., 2022). Subsequently, modern forestry ca 200 years BP affected wetlands again (Bak et al., 2024). Combining palaeoecology with experiments and monitoring provides a complete picture of changes connected with hydrological change (Jassey et al., 2018 03; Lamentowicz et al., 2019). Much stronger cooperation between scientists to better protect wetland ecosystems is now needed. In the recent two decades, scientists better understood GHG fluxes vs hydrological conditions using chamber and EC approaches {Evans et al., 2021, #180210}. However, we need a deeper understanding of palaeoecology and long-term processes reaching wetlands' origin on Earth to predict their future during the progressing ecological crisis.

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PLENARY TALKS

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Mariusz Lamentowicz

Mariusz and his team at the Climate Change Ecology Research Unit (Adam Mickiewicz University, Poznań, Poland) use palaeoecological and experimental approaches to understand the impact of current and past climate changes and anthropogenic disturbances on peatlands. He conducted the research on the data from peatlands in, e.g., Siberia, Mongolia, Central America, Amazon, Switzerland, Falkland Islands, the Czech Republic, Lithuania, Latvia and Estonia. Furthermore, Prof. Lamentowicz is an expert in palaeoecology and the ecology of testate amoebae (Protista). He cooperates with specialists studying the morphology and taxonomy of these organisms. His long-term aim is the implementation of interdisciplinary research on the impact of climate change on peatlands through the integration of monitoring, experiments, and paleoecology. Recently, Prof. Lamentowicz has worked on questions related to peatland restoration and scientific communication with stakeholders. Furthermore, he is involved in climate education, scientific communication and communication with non-scientific audiences through podcasts, movies, lectures and seminars.

PLENARY TALKS

Thank you Biebrza!

Martin Wassen

Copernicus Institute of Sustainable Development, Utrecht University,
Utrecht, the Netherlands

Thank you Biebrza !

What started almost 40 years ago, when I visited Biebrza for the first time in 1985 has enriched my life in many ways. The landscape, the ecosystems, the hydrology, the people, the friends and all the adventures I experienced during these almost 4 decades. Doing field work together, gaining insight into how this extraordinary ecosystem works, experiencing the darkness at night, the quietness, the wildlife, the cultural heritage, how people can live in harmony with nature, the history with its bright but also dark sides, the happiness we shared at a bonfire or being on my own for a day in the marshes. All this I cherish with gratitude. I have, not only as scientist, but also as a person benefitted enormously from Biebrza.

Today in my presentation I will take you on a tour. I will travel through time over the past 40 years of Polish – Dutch cooperation. On the way I will highlight projects in which various consortia of researchers have worked together in unravelling the secrets of Biebrza leading to a deeper insight into the processes and the functioning of the system and how these have contributed to protection and management. On behalf of all Dutchmen that worked in Biebrza I would like to express our sincere gratitude.

Thank you Biebrza !

Martin Wassen

Professor of Environmental Sciences who studies terrestrial and wetland ecosystems and their functioning in a changing world (land use change, water management, global change). His key expertise is in eco-hydrology, landscape ecology, biogeochemical cycles, biodiversity and nature conservation. He has given > 200 presentations, convened a number of top class symposia and conferences and has published > 180 peer reviewed articles in refereed journals. He was head of the research group Environmental Sciences (2000-2023) and was head of the Copernicus Institute of Sustainable Development (2007-2016) at the Faculty of Geosciences, Utrecht University. He acts as a member of external review commissions (Dutch National Research Council (NWO), EU, external academic research assessments) and he is a regular reviewer of manuscripts for high impact journals. He is member of the Editorial Board of the Journal of Water and land Development. He was awarded with a honorary medal by the Institute for Land Reclamation and Grassland Farming, IMUZ, Poland (2005) and in 2007 and 2024 he received a honorary award of Warsaw University of Life Sciences, SGGW, Poland. He is active in several advisory commissions and committees on nature protection, nature restoration, biodiversity and land use in the Netherlands. He is chairing the European Bison Re-introduction Project, National Park Zuid Kennemerland and is member of the Advisory Committee National Parks for the minister of Agriculture, Nature and Food supply (NL) and is a member of the Dutch Ecological Authority. He was vice-president of the board of Vereniging Natuurmonumenten (2007-2015), an influential NGO for nature protection in the Netherlands with c. 900.000 members.

PLENARY TALKS

Time to restore. What can science do to bring power to the peatlands?

Rudy van Diggelen

Department of Biology, University of Antwerp, Belgium

Peatlands have declined worldwide, especially in Europe, particularly in Western Europe, where many have simply vanished. Almost all remaining peatlands are so severely degraded that they have become environmental problem areas. To reach a sustainable future peatland restoration is therefore essential. The European Commission has recognized this and included peatland restoration as a priority target in an ongoing legislation attempt to reverse further nature degradation in Europe. This proposed Nature Restoration Law formulates binding targets for nature restoration throughout the EU and has the final goal that all European ecosystems are in need of restoration by 2050. Note that the proposal does not say that the restoration has finished by 2050 but instead that it is in progress by then. The Commission sees restoration as a process, not necessarily an endpoint.

Despite this, according to some relatively modest target, the NRL proposal has led to much agitation in interest groups. The agricultural lobby has campaigned massively against the proposal. That lobby was rather successful. At the moment of writing (spring 2024), even a significantly watered-down version of the original proposal has still not been accepted by the member states.

In my contribution, I will describe how the process has developed and analyze the role of scientists therein. I will assess the positions of the different interest groups and discuss opportunities to cooperate with crucial stakeholders in order to bring back the power to the peatlands. I will discuss possible restoration pathways outside the NRL and identify areas where scientists can play an important role.

Rudy van Diggelen

Professor Emeritus at the University of Antwerp, specializes in Restoration Ecology, particularly in wetlands. With extensive experience spanning academia and practical conservation, he focuses on biodiversity conservation and nature restoration, emphasizing water-soil-nutrient-vegetation relationships. Dr. van Diggelen holds influential roles, including chairing the European chapter of the Society for Ecological Restoration and leading the review commission on Restoration strategies Nitrogen for the Dutch Ministry of Agriculture. He advises on peatland and wetland management globally, shaping environmental policies. As a prolific author, his work bridges scientific research with practical applications, contributing significantly to ecosystem conservation and restoration.

PLENARY TALKS

Wetland restoration in the National park "Bielaviežskaja pušča" – the Belarusian part of the Bialowieza forest. Summary of the two decades of work

Viktar Fenchuk

Frankfurt Zoological Society, Frankfurt, Germany

National park "Bielaviežskaja pušča" covers an area of over 150 thousand hectares of which 82,5 thousand hectares constitute the Belarusian part of the cross-border belarus-polish UNESCO World Heritage Site Bialowieza forest.

Forests of Bielaviežskaja/Bialowieza were developing in the conditions of stable hydrological regime and high waterlogging with up to 30% of the area covered in wetlands and mires. Drainage and land improvement activities started on the territory of Bielaviežskaja/Bialowieza in the 19th century, continued in 1920-1930's and peaked during soviet times in 1950-1960's. As the result, over 50% of mires were drained, the majority of rivers canalized and an extensive system of drainage canals created. Such large scale drainage caused a general drop in the ground water level on the larger part of Bielaviežskaja pušča by 0,5-1,5 meters leading to cascade effects in forest ecosystems (Grummo et al., 2021).

First wetland restoration activities on the territory of the National park were conducted at Dzikaje mire in 2006 under coordination of APB-BirdLife Belarus as part of implementation of the site management plans for three key breeding sites for the globally threatened Aquatic warbler *Acrocephalus paludicola* developed in 1998. Following this work, the need for wetland restoration appeared in the Park's Management plan in 2008 (*Management plan*..., 2008).

The first complex inventory of potential wetland restoration sites was implemented in 2010. The inventory focused on melioration systems – drained mires and screened the state of 14 sites, of which 10 sites were identified as requiring restoration (Kozulin et al., 2010). In 2012-2013 the second inventory focused on small and seasonal watercourses in the central part of Bielaviežskaja pušča and reviewed the state of 30 linear objects (channels, streams, rives), of which of which only 8 were of natural origin. Subsequent and prioritization selected 8 objects grouped in 3 sites (Arnolbik et al., 2013) for priority restoration.

In December 2013 a Memorandum of Understanding outlining key priorities for joint work was concluded between the National park "Bielaviežskaja pušča", APB-BirdLife Belarus and Frankfurt zoological society. This cooperation gave an impetus to wetland restoration activities. Basing on the results of the inventories, planning of restoration works started in 2014 and by 2023 the restoration works were implemented on 10 sites with the total area of 3 664 hectares. The smallest restoration site was 36 ha (canal in the upper course of Salomienka river) and the largest – 1 238 ha (Zarkauščyna forest drainage network) (Tab. 1., Fig. 1).

The third stage of screening was implemented in 2021 (Grummo et al., 2021) focusing on pealtands and with the account of restoration works implemented in 2014-2021. Preliminary list of restoration sites included 34 territories, located in different functional zones of the National park. Further field work narrowed down this list to 19 sites with the area of 29 139 hectares, ranging from 57,8 ha (Panasiuki) to 13'610 ha (Arlova mire). This list constituted the workplan for peatland restoration in Bielaviežskaja pušča until 2030.

PLENARY TALKS

Table 1. Wetland restoration sites in the National park "Bielaviežskaja pušča"

#	Site name	Year of completion of restoration works	Area [ha]	Site type
1	Dzikaje mire	2006	n/a*	Natural fen mire
2	Baruščyčy	2016	37	Drained fen mire
3	Plianta	2016	91	Drained fen/meadow
4	Upper Salomienka river	2016	36	Forest drainage channel
5	Dziki Nikar	2017	1164	Drained fen mire
6	Papialiova	2018	300	Drained fen mire
7	Dzikaje - Kliepačy	2019	330	Drained fen mire
8	Salomienka river	2019	138	Canalized river
9	Zarkauščyna drainage network	2021	1238	Forest drainage channel network
10	Zubryca	2023	92	Drained fen mire
11	Halieva balota	2023	239	Drained fen mire
	Total		**3664**	

* *Impact area estimation is not available*

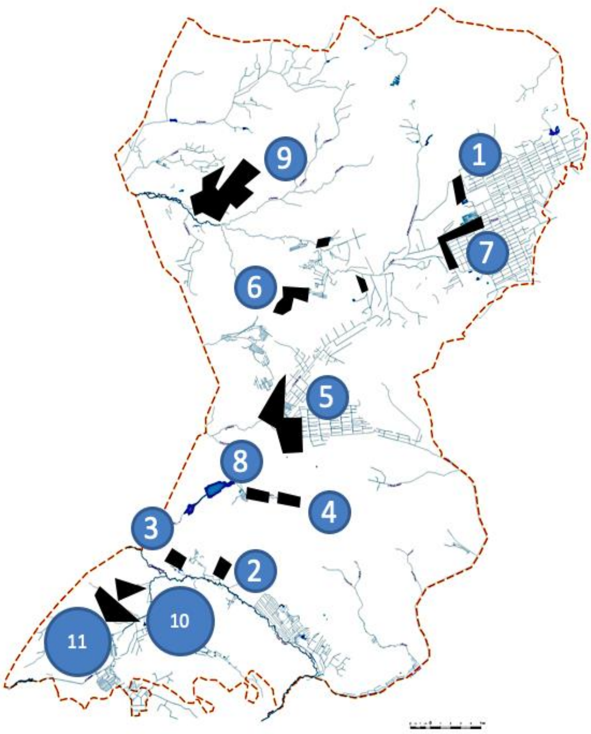

Fig. 1. Wetland restoration sites in the National park "Bielaviežskaja pušča" entre figures. Numbers correspond to those in Table 1.

PLENARY TALKS

The decade of restoration works showed that the cycle from the concept to completion of construction is taking over two years and the average pace of restoration of one site per year. Hence, the needs for restoration are much larger than the capacity to implement them, and the existing restoration plan constitutes an ambitious programme.

Current border wall construction on Belarus/Polish border will likely create additional problems with hydrological regime and will require even more resources to mitigate them on the both sides of the border.

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Viktar Fenchuk

A wetland conservationists and wildlife biologist from Belarus. He is a former director of APB-BirdLife Belarus, the country’s largest environmental NGO and the leader of the international wilderness conservation programme for APB and the Frankfurt Zoological Society. Viktar was one of the initiators and leaders of several large-scale peatland restoration projects and programmes in Belarus. He was active in establishing effective cooperation between different partners working in wetland conservation and restoration in Belarus and abroad, due to which about every second hectare of restored peatlands in Belarus was restored by or with input from APB. As part of APB and governmental cooperation, he was many times part of Belarus national delegations to UNFCCC and Ramsar Convention meetings and organizer of parallel events promoting peatland restoration and sharing Belarus’ experience in rewetting, GHG balance assessment and biodiversity monitoring. Following the 2020 presidential elections in Belarus, Viktar was arrested and sentenced to 2.5 years of imprisonment for participating in peaceful protests. He currently continues to work for the benefit of wetlands in Poland.

SOCIETY of WETLAND SCIENTISTS
Europe Chapter

CONTRIBUTED TALKS

SESSION I - LEARNING FROM THE PAST

Island, lake and wetland: a palaeoecological and geoarchaeological reconstruction of Early Bronze Age and Early Iron Age settlements in Bruszczewo (Western Poland)

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INTRODUCTION

The connection between the Bronze and Early Iron Ages people and the former wetlands in Central Europe has been a subject of study for decades but seen mostly in the scope of conventional archaeological research. However, in recent years, a growing number of multiproxy studies of environmental archaeology brought to light new perspectives on reconstructing the impact of prehistoric people on wetlands, also in the light of high-resolution chronological schemes (i.e. Ghilardi et al. 2008; Doyen et al. 2016; Gałka et al. 2022). In this study, we look at the environmental reconstruction of a wetland associated with a particular site in Western Poland – Bruszczewo.

The Early Bronze Age settlement in Bruszczewo belongs to the most known sites in terms of the earliest fortifications in Central-Eastern Europe (Czebreszuk et al., 2004). It was inhabited between app. 4200 and 3400 BP by the people of the Unetice culture – one of the first proto-civilizations in this part of Europe (Czebreszuk et al., 2015). In the same place, after a few hundred years, people of Lusatian Urnfields culture (Fig. 1) established their ritual centre and cremation cemetery that thrived during the Late Bronze and Early Iron Ages (app. 2900 – 2400 BP) (Ignaczak 2015).

The archaeological site is located on a small hummock extending eastwards from the slope towards a peatland of the Samica River valley (Fig. 1). The earlier studies of the site provided the first evidence for the existence of a lake surrounding the peninsular in prehistory, however, based only on a single core and low-resolution radiocarbon dating of events (Haas et al., 2010).

In this study, we have combined the GIS, geophysical, palaeoecological and geological data approach to investigate the changing ecological conditions and reveal its meaning and connection to well-recognized settlement processes in Bruszczewo.

METHODS

Our research consisted in the first place of LIDAR scanning to obtain insight into the extent of the former wetland. A 1x1m ALS grids were analyzed in terms of wetness index, relative elevation and slope analysis. Next, the magnetometry (Bartington Grad 601) and georadar (Leica DS200) prospection took place across the former basin to obtain information about the depth of organic deposits. Also, a geophysical survey was taken in the area of a small hummock in the middle of the basin (Fig. 1) to verify the hypothesis of the existence of a probable island.

Afterwards, a series of cores were taken, using mechanical vibra-coring and conventional *instorf* corer. A total number of 5 profiles was obtained to reconstruct the stratigraphy and to provide the material for palaeoecological reconstruction (Fig. 1).

For this purpose, the core IT_1 was chosen being the closest to the EBA and EIA settlement. 17 AMS radiocarbon dates were used to provide a high-resolution age-depth model spanning the sequence between the EBA and Medieval times. The sediments within the core were subjected to palynological (including NPPs), sedimentological and geochemical analyses, and diatom identification. The remaining cores were subjected to macroscopic description and radiocarbon dating within the borders between different lithological units.

We have also used the results of former archaeological excavations on the settlement, as well as the effects of archaeological surface survey around the Samica Valley to correlate our study with the existing knowledge on the prehistory of the area.

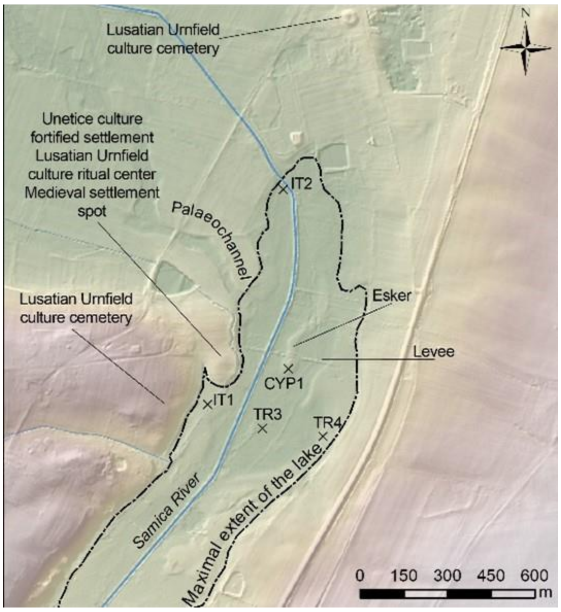

Fig. 1. The reconstruction of Bruszczewo palaeolake and fen based on coring data

RESULTS AND DISCUSSION

The stratigraphy of the basin, according to coring and AMS dating, represents the evolution of a postglacial lake, which has gradually started diminishing around 2900 BP and turn into a fen around the threshold of the eras, and lasted until the Medieval period. The lake's cross-section shows a great depth (up to 9.5 m of gyttja and peat deposition in the central part) with a high inclination of its slopes, which might have supported the defensive traits of the fortified settlement at its western part. Despite the gradual terrestrialization of the lake, around 3800 BP, it underwent transgression, as documented in the eastern part of the basin by the occurrence of sandy layers overlayed with gyttja. This event corresponds directly with the archaeologically documented erection of a wooden fascine structure by the EBA people at the same time. Its location in the shoreline area of the fortified settlement indicates the necessity for reinforcing the land from wave erosion and water entering the inhabited area.

Both events – long-lasting terrestrialization and short-term transgression, do not fit into any recognized climatic events that might have provoked these changes. Therefore, our focus is put on the anthropogenic factors such as erosion or deforestation happening at the time of the EBA and EIA (Niebieszczański et al., 2023).

The palaeoecological reconstruction based on IT_1 coring provided crucial information about the main events of anthropopressure in the area. We have identified at least 4 periods (EBA, LBA, EIA and Early Medieval) of intensified human occupation, separated by decreased settlement activity markers in the proxies.

As far as the bottom of the valley is overgrown by grasses and meadows, there is no possibility of conducting the conventional surface survey there. However, the geophysical survey in the area of the suspected island revealed the existence of anomalies resembling archaeological features in the middle of the wetland. A series of drillings on a small hummock resulted in discovering dry episodes on the suspected island during the EBA and EIA. Within the drilled sediments, we have also encountered numerous pottery fragments as well as animal bones app. 1.2 m b.g.l. (Niebieszczański et al., 2022).

CONCLUSIONS

Our research has shown the great potential of wetland environments for supporting the archaeological knowledge about past societies and their relation with the surrounding waterscapes. The reconstructed scheme of changes within the basin point corresponds directly to the major events in the human occupation history of the area (emergence of fortified settlement, its demise, fascine construction, occupation of the island, etc.). Each settlement phase faced different ecological conditions and events (lake, transgression, terrestrialization, fen) giving the inhabitants different opportunities but also new challenges. The investigation in Bruszczewo also emphasize the need for special attention to wetlands in terms of archaeological prospection, as until now the conventional surface surveys omitted these areas due to the lack of a proper, geoarchaeological approach.

ACKNOWLEDGEMENTS

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SESSION I - LEARNING FROM THE PAST

The temporal variability of the Holocene $CaCO_3$ deposition at four alkaline fens in the young glacial area of central Europe

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INTRODUCTION

Calcium carbonate depositing alkaline fens, are a specific type of wetland, the functioning of which depends on the supply of Ca^{2+} enriched groundwater at ambient temperature. Precipitation of $CaCO_3$ (tufa), results from loss of CO_2 due to biotic and abiotic processes as the groundwater emerges at the fen surface. Peat and tufa intercalations are characteristic deposits of alkaline fens. Studies of the recent alkaline fen condition and recognition of the palaeoecological history of those ecosystems are important for at least because of two reasons. Firstly, the alkaline substrate (as assured by $CaCO_3$ precipitation), makes alkaline fens a habitat for many rare and protected species of plants and animals. Since the number of alkaline fens is declining this ecosystem is protected by the European Union law. Investigation of the palaeoevnironment of the alkaline fens reveals their past development pattern, which is crucial for conservation issues. Secondly, alkaline fens are carbon sinks, since they entrap C in the form of the organic matter and $CaCO_3$.

This study aims to identify the timing of tufa deposition at four alkaline fens located in north-eastern Poland and Latvia, within the extent of the Weichselian glaciation: Turtul (Apolinarska et al., 2022, 2024), Puszcza Romincka (Apolinarska et al., 2023), Maitiku (Kiełczewski et al., unpublished), and Lustūžkalns (Apolinarska et al., under review). We also aim to recognize the factors responsible for the temporal variability of tufa deposition.

METHODS

The geochemical composition of the sediments, including the percentage concentrations of $CaCO_3$, measured at 1-cm intervals in the sediment sequences investigated, was determined using the loss on ignition analysis (LOI) following the procedure described by Heiri et al. (2001). The chronology of the sediments is based on ^{14}C dates from terrestrial plant macrofossils.

RESULTS and DISCUSSION

The time frames of $CaCO_3$ accumulation varied between the fens. In north-eastern Poland, tufa was deposited between ca. 11650 and 50 cal yr BP on Puszcza Romincka fen (Apolinarska et al., 2023) and between ca. 9250 and 5400 cal yr BP on Turtul fen (Apolinarska et al., 2022). The early Holocene onset of $CaCO_3$ accumulation was associated with the activation of groundwater circulation following permafrost degradation. The decline in tufa deposition ca. 5400 cal yr BP in Turtul was likely related to climate cooling in the mid-Holocene. Declined temperatures affected the conditions of tufa precipitation and indirectly decreased the Ca^{2+} supply controlled by chemical denudation of the scattered $CaCO_3$ from glacial sediments in the aquifer. Also, after progressive leaching during the early Holocene, this carbonate reservoir became a less efficient

Ca^{2+} source (Apolinarska et al., 2024). The Holocene-long tufa deposition at Puszcza Romincka fen, exceptional in north-eastern Poland, likely resulted from site-specific hydrogeological conditions assuring an efficient supply of Ca^{2+}-rich artesian waters.

At Maitiku (Kiełczewski et al., unpublished) and Lustūžkalns (Apolinarska et al., under review) fens, enhanced tufa accumulation has been observed only since ca. 3500-3200 cal yr BP, when the increased climate humidity resulted in increased water tables at bogs and fens in Latvia (Kalnina et al., 2015). This Late Holocene increase in the water tables was triggered by the termination of the frequent anticyclonic circulation over the Scandinavian Peninsula (Antonsson et al., 2008) which brought very warm summers with reduced precipitation, and return to the predominately zonal mode of circulation (Heikkilä et al., 2010), and the influx of humid westerlies over Fennoscandia and Eastern Baltic Region. In addition, the concurrent cooling trend contributed to the increase of the effective precipitation, which also increased the groundwater tables. The Palaeozoic limestone bedrock, an inexhaustible source of Ca^{2+} ions, assures intensive $CaCO_3$ precipitation at Latvian sites as long as the groundwater level remains high and the fens are not affected by humans.

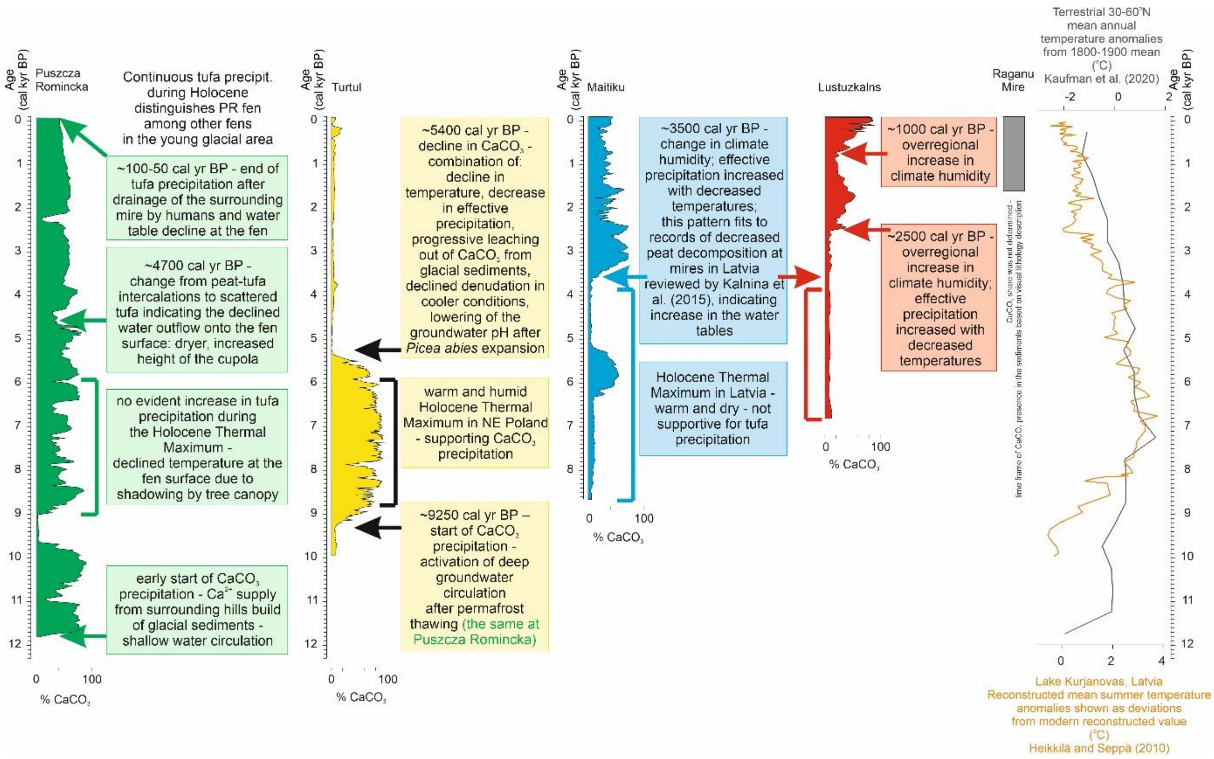

Fig. 1. The timing of tufa deposition at four alkaline fens located in NE Poland and Latvia, within the extent of the Weichselian glaciation: Puszcza Romincka (Apolinarska et al., 2023), Turtul (Apolinarska et al., 2022, 2024), Maitiku (Kiełczewski et al., unpublished), and Lustūžkalns (Apolinarska et al., under review).

CONCLUSIONS

The high temporal variability of tufa deposition at the alkaline fens investigated can be attributed to the complexity of factors controlling $CaCO_3$ precipitation. The most critical are local climate fluctuations including both temperature changes and shifts in precipitation, type and richness of Ca^{2+} source, and hydrogeological conditions.

ACKNOWLEDGEMENTS

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SESSION I - LEARNING FROM THE PAST

How paleoenvironmental data obtained from peatlands (and lakes) can fill the gap in archaeological and historical sources

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INTRODUCTION

In recent years, there has been a significant increase in the use of high-resolution methods for reconstructing past environments. It involves reconstructing past environmental changes as accurately as possible, both in terms of placing events precisely on the time scale (absolute dating), as well as minimizing temporal gaps between samples. Analysis of peat and lake deposits yields valuable insights into historical human impacts on the environment.

In some cases, the high-resolution multiproxy approach facilitates an "update" of archaeological knowledge. This approach seems to have even more justification when archaeological recognition is inadequate, due, among other things, to the lack of continuous finds that make it impossible to assign them to a definite age.

AIM AND METHODS

This presentation aims to explore the opportunities and limitations of the high-resolution palaeoecological approach, using selected paleoecological studies primarily from the Greater Poland area (derived from peatlands and lakes) as examples.

We show how the combination of diverse proxies like pollen, coprophilous fungi, microcharcoal, testate amoeba, and macrofossils from these ecosystems is highly effective in revealing past anthropogenic (and related hydrological) changes.

MATERIALS

To enhance our understanding of history, we collected cores from various locations such as Kazanie mire, Lednica lake, and peatlands near Giecz and Bruszczewo. These sites provide valuable insights into how the natural environment changed near early medieval strongholds. A detailed time scale was established for these sites, with at least one radiocarbon date per 10 cm of core, allowing for precise dating of past events. Furthermore, dense sampling (every 1 or 2 cm) was conducted to minimize the time gap between samples.

RESULTS AND CONCLUSIONS

The findings from these studies have the potential to contribute to filling the archaeological and historical gaps regarding past transformations of the environment by human activities, particularly over the past 2000 years.

Palaeoenviromental reconstructions from peat and lake deposits were crucial in determining the onset of human impact intensification near the sites, likely linked to Slavic influences in the early Middle Ages. Additionally, these results revealed spatial variations in these patterns. Importantly, reconstructing past environments provided insights into the environmental changes near the sites, closely tied to the emergence of the Piast State in the 10th century.

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SESSION I - LEARNING FROM THE PAST

Holocene wetness and growing season changes in Linje mire, Poland

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INTRODUCTION

In this multi-proxy study, we present an exceptional peat record from Central Europe that represents the environmental dynamics of the whole Holocene. This 12-meter core was extracted from the center of Linje mire, a protected peatland in the Chełmińskie Lakeland in northern Poland.

We have investigated local vegetation and mire surface wetness changes based on plant macrofossil and testate-amoebae analysis. In addition, we intend to explore past spring seasonality patterns in the Early and Late Holocene based on a microphenological analysis of subfossil dwarf birch (*Betula nana*) leaves.

METHODS

Paleoecological proxies: In 2019, a 12 m length peat core was extracted from the center of the ombrotrophic Linje mire. The chronology of the peat profile is based on ×20 AMS dates. Testate amoebae analysis (Booth et al., 2010) was undertaken to reconstruct palaeohydrological conditions at the site. Plant macrofossil analysis follows the Quadrat and Leaf Count protocol (Mauquoy et al. 2010). Subfossil *B. nana* leaves were picked out and stored separately to perform a microphenological analysis of their cuticles (Wagner-Cremer *et al.,* 2010; Amon et al., 2022).

Microphenological training set: Ercan et al. (2021) have already demonstrated that *Betula nana* epidermal cell properties are responsive to warming experiments in Linje mire. We intend to analyze the epidermal cell growth of mature *B. nana* leaves collected from Linje mire between 2018 and 2024 to obtain a high-quality local training set considering the microclimatic conditions of the site. Epidermal cell properties, such as the size and shape of the cells, will be quantified as undulation indexes (UI). This data will be compared to local meteorological data to develop an accurate training set for past growing season estimations following Wagner-Cremer et al., 2010.

RESULTS and DISCUSSION

Sphagnum stratigraphy shows a clear division between the Middle Holocene hummock-peat period (ca 7600–4600 cal. BP) with *Sphagnum sect. Acutifolia* (*S. rubellum* & *S. fuscum*) and hollow peat periods in the Late and Early Holocene with *Sphagnum sect. Cuspidata*, aligning with the climatostratigraphic division of the Holocene (Hang et al., 2020).

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The beginning of Linje mire (ca. 11,550 cal. BP) is marked by minerotrophic brown moss species such as *Scorpidium scorpioides* and testate amoebae taxa *Centropyxis aculeata* and *Cyclopyxis arcelloides*. Starting with minerotrophic *Sphagnum contortum,* peatmosses were present in the peatland from ca. 10 920 cal. BP onwards.

The most common species of testate amoebae in the peat core are *Archerella flavum* and *Hyalosphenia papilio*, which indicate the relatively stable and high water table throughout most of the timeline. However, drier conditions were present during the first half of the Holocene Climatic Optimum (ca 7600-6500 cal. BP). A higher abundance of species like *Galeripora discoides* and *Alabasta militaris* during the last 200 years indicates drier conditions and more fluctuating water table. Also, *Trigonopyxis arcula* and *Cyclopyxis arcelloides* indicate an additional mineral input during this period.

For the microphenological analysis, suitable subfossil leaves of the glacial relic *Betula nana* were found from two time periods: 11 160-8200 cal. BP (early Holocene) and 4400-1850 cal. BP (Late Holocene). We will estimate the growing season length after completing the local microphenological training set.

The continuous peat record for over 11 500-year-old Linje mire shows exceptionally well dry and wet phases and anthropogenic disturbance episodes. These results will be complemented by growing season reconstructions as well as pollen and non-pollen-palynomorph data that will strengthen our interpretation of climatic signal.

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SESSION I - LEARNING FROM THE PAST

Exploring the effects of human activity and fire on vegetation, hydrology and carbon accumulation in Mustjärve, Northwest Estonia

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INTRODUCTION

Peatlands are one of the most important ecosystems for carbon storage, storing 25-30% of global soil carbon in just 3% of Earth's terrestrial surface. However, many peatlands are subject to pressure from climate change and human activity, which inhibit peat's natural carbon cycle, turning them from carbon stores, to carbon sources. One of the most damaging human activities is peat draining, where water is diverted away from the peatland via ditches. This causes the water table to decrease, significantly impacting peat accumulation and releasing stored carbon as the sediment degrades as it dries. When peatland hydrology is impacted, vulnerability to fire also increases; fire is one of the greatest threats to peat, destroying the sediment itself and releasing stored carbon. Fire frequency is predicted to increase due to more frequent and severe droughts in some areas, and increasing human activity in areas where peat can form (particularly in the Northern Hemisphere). These trends, if realised, can accelerate climate warming as previously stored carbon is released into the atmosphere.

STUDY SITE AND METHODS

The focus of this study is Mustjärve bog, an ombrotrophic peat bog in northwest Estonia. Two metres of sediment was collected; the first metre using a Wardenaar corer, the second using an instorf corer. Our project reconstructs fire regimes (charcoal), vegetation dynamics (plant macrofossils and palynology), peatland hydrology (testate amoebae) and carbon accumulation (Loss on ignition) to analyse how the site has been impacted by past changes in climate and human activity. We also used historical data (population, past climate and archaeological records) to better understand drivers of changes uncovered in the record. CONISS analysis based on the palynological data identified five significant zones.

RESULTS and DISCUSSION

Our data reveals that whilst climate was the predominant influence on Mustjärve at the start of the record, increasing anthropogenic activity has overtaken climate, especially after ca. 400 AD. Zone 1 and the first half of Zone 2 are characterised by limited human activity, as the water table steadily rises and falls, probably within its 'natural' cycle. Early sediments are dominated by *Sphagnum* sect. *Cuspidatum*, however after the water table decrease ca. 250 BC drier taxa such as Ericaceae and *Sphagnum* sect. *Acutifolia* increase. The latter half of Zone 2 differs from the first as the water table appears to be disturbed, resulting in more erratic, sudden increases and decreases, especially after ca. 250 AD. Zone 3 includes evidence for increasing human activity, with a major fire period ca. 440-450 AD. This zone is notable for a sudden increase in *Calluna Vulgaris*, which likely exacerbated the presence of fire in this period.

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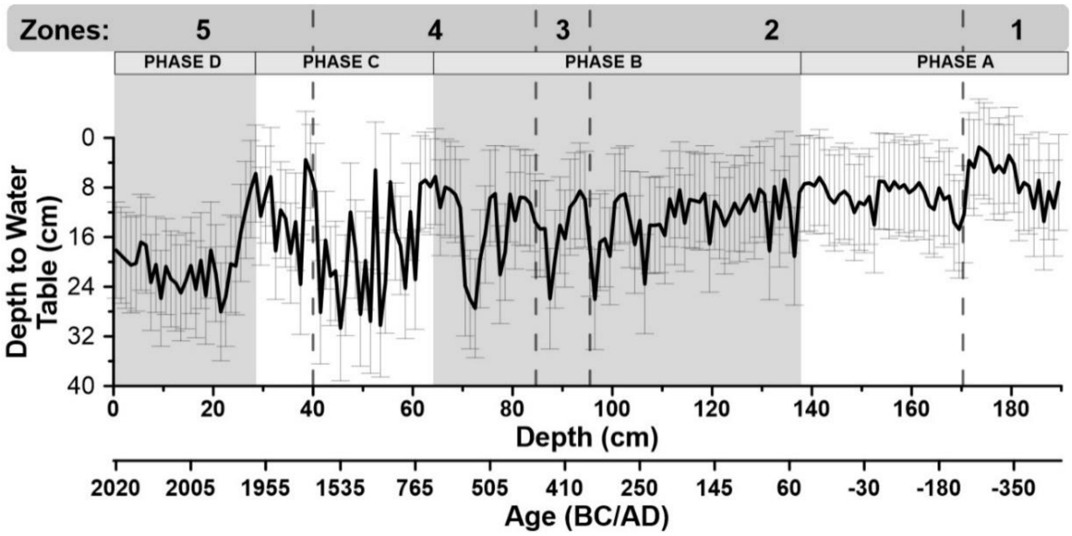

Fig. 1. Depth to water table (cm) reconstructed by testate amoebae. Zones dictated by CONISS are separated by dashed lines. Phases dictated by observed changes in water table trends are shown by alternating grey/white shading.

In Zone 4, the water table fluctuates near-constantly. The last major influence of climate is seen as a water table drop ca. 525 AD, likely a result of drought conditions. There is also evidence of increasing human activity around this time though, increasing Poaceae (and other taxa associated with agricultural activity) after ca. 530 AD. The water table continues to fluctuate after ca. 750 AD; this coeval with frequent fire events, indicating constant disturbance by human activity. As a result of an unstable water table, vegetation dynamics also shift frequently; the makeup of *Sphagnum* is especially volatile in this period. Carbon accumulation is extremely low in this period, whilst bulk density increases to its peak in the record. Zone 5 continues this trend until ca. 1960 AD, where a sharp decrease in the water table occurs, most likely a result of peat drainage post-World War II. This significantly impacts the height of the water table, as although it is more stable than Zone 4, it does not rise above 16cm, despite a lack of local fire events in this period. In the last 20 years Mustjärve has become drier, indicated by the encroachment of *Pinus Sylvestris* and *Betula Nana* onto the site. We find little evidence for a significant climatic influence on Mustjärve from 500 AD onwards, as increasing anthropogenic pressure appears to override the palaeoclimate signal seen in Zones 1 and 2.

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SESSION I - LEARNING FROM THE PAST

The importance of water table depth thresholds in peatlands' restoration

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INTRODUCTION

Peatlands store 25% of the soil's carbon (C) stock; these ecosystems act as sinks of C in their natural status (Loisel et al., 2021). However, peat degradation in disturbed peatlands represents 5% of the global anthropogenic greenhouse gas emissions (GHGs) (Leifeld & Menichetti, 2018). That is why peatland restoration is a key process to meet the United Nations' Sustainable Development Goals (SDGs) (Tanneberger et al., 2021).

During the peatland restoration process, the water table level is increased (rewetting) to slow down the decomposition with waterlogged conditions. Multiple challenges are present in choosing the right restoration process in each case, and as stated by Zak & McInnes (2022), a controlled and progressive rewetting is a more feasible strategy to control nutrient mobilisation and GHGs emissions. The progressive recovery of the "natural" wet status is accompanied by changes in the vegetation (immigration of peat-forming plants), which completes the restoration process.

The study of vegetation succession related to moist conditions is often analysed through palaeoecological reconstructions, revealing the long-term context. However, to implement the right restoration strategies, we still need to better understand this process at a short time scale. A meta-analysis was performed, including articles from 1983 to 2022 on bogs and fens, to explore the thresholds of water table depth (WTD) in peatland ecosystems translated into vegetation succession.

METHODS

The articles were selected from the Web of Science (WoS) search engine based on a filtration process that considered publications spanning the past forty years, from 1983 to 2022, accessed on 25th January 2023. The inclusion criteria involved articles with titles or abstracts containing keywords such as "water table," "water level," or "groundwater level," as well as "peatland," "bog," or "fen". Out of the initial pool of 1587 articles, a total of 100 articles were chosen for inclusion. Up to 77% of the articles in this review were published within the last ten years.

The vegetation data analyses encompassed the following aspects:

A total of 123 fens were included in the analysis, with 62 classified as non-degraded/pristine, 48 as rewetted, and 13 as drained.

Additionally, 40 bogs were analysed, with 16 categorised as drained, 19 as non-degraded/pristine, and 5 as rewetted.

The peatlands were subclassified as drained, rewetted/restored, and natural/pristine, with no distinction between bog and fen. However, as mentioned, the quantity of data from fens is superior. The selected 100 publications provided data on the annual or seasonal average WTD and the percentage coverage of each PFT to study plant functional types (PFTs) distribution through the WTD. The dominant PFT was determined by selecting the PFT with the highest coverage reported.

Lastly, the statistical methods used to determine the thresholds of WTD was the segmented linear regression with 50 bootstraps and a tolerance of 1e-05, employed for tipping point determination (Jassey et al., 2018; Muggeo, 2017). The breakpoints were selected at points where the vegetation density distribution exhibited the most significant changes while experiencing the least variation in WTD, indicating sudden changes. The analysis was conducted on two sets of data: values in the right tail part of the Gaussian distribution (right of the maximum density) and values in the left tail part of the Gaussian distribution (left of the maximum density).

RESULTS and DISCUSSION

The analyses clearly distinguish between the behaviour of PFTs and changes in WTD depending on peatland status (natural, rewetted/restored, drained). In the natural/undisturbed status, the distribution of mosses, forbs and graminoids dominance through the WTD is similar, with 50% of the data ranging from -10 to 4 cm. Because shrubs and trees tolerate less the waterlogged conditions, their dominance is shifted to deeper water tables with 75% of the peatlands where these PFTs dominate showing WTDs below -18 and -5 cm (Table 1). When the dominance of these PFTs is analysed in drained peatlands, the differences between them increase. In this case, forbs dominance practically disappears, with insufficient data (<10) to correctly compare the distribution through WTDs. Graminoid dominance is spread from -45 to -21 cm, showing the highest adaptation to deeper WTDs, while mosses dominance ranges from -32 to -15 cm, with the highest density of data between -25 and -10 (Table 1). The data of shrubs and trees shows the narrowest distribution around -21 ± 10 cm and -30 ± 10 cm, respectively. Lastly, rewetted peatlands seem to diminish the differences between PFTs, partly recovering the similarities between the distribution of forbs, mosses and graminoids. However, they present deeper water tables and share their distribution with shrubs (Table 1). In the case of rewetted, as same as it happened with forbs in drained peatlands, the presence of rewetted peatlands with trees as dominant PFT is not high enough to compare it with the rest of PFTs.

Table 1. Statistics of peatlands by status (natural, drained, rewetted). The upper threshold and lower thresholds calculated from segmented linear regression and Q1, Q2, and Q3 represent the quartiles of 25%, 50% and 75%.

Plant Functional Type	Upper threshold	Lower threshold	Q1	Q2	Q3
Mosses	15.8|3.3|25.4	-29.1|-50.7|-40.5	-12.3|-31.7|-25.1	-4.2|-19.5|-10.1	-1|-14.9|-1.5
Forbs	13.9|-49|68.4	-24.2|-138.2|-31	-11.4|-45|-10	-1.5|-93.6|-7.38	-4.6|-74.8|30.5
Graminoids	18.5|-27.5|18	-28.4|-59.6|-26.4	-7|-45|-112.4	-3|-41|-1	4|-21.9|10
Shrubs	-4.7|-17.8|-1.6	-29.9|-29.5|-37.8	-27.9|-24.6|-12.1	-20.8|-21.5|-12.1	-18.1|-20.3|5
Trees	11.1|-25| -	-15.5|-45.3| -	-14.8|-40| -	-9|-36.4| -	-5|-30| -

The thresholds established for each PFT and peatland status greatly differ; however, the highest similarities seem to be found between natural and rewetted status (Table 1). The shift from forbs-mosses-graminoids to shrubs-trees dominances is placed with WTDs around -18 cm for natural peatlands, while it is not possible to clearly establish it in drained and rewetted peatlands (data not shown). The higher differences between PFT's abundance and different WTDs in drained peatlands are probably due to their different adaptation capabilities. This has been observed by other researchers, showing how some vascular plants can even respond positively to higher WTD, while in moss-dominated peatlands, the strategy is reversed, tending to a resources-conservative one, thus reducing growth rates etc. (Laine et al., 2021).

Rewetting is a solution to recover peatlands' natural status and avoid further emissions of CO_2. This strategy effectively reduces emissions, and its prompt implementation yields optimal results (Günther et al., 2020). Highly drained peatlands, during an extended period, have the extra difficulty of the shift of vegetation, as was also observed in this review; that is why, though the emissions of CO_2 are majorly reduced, the peatlands do not always return to their previous "natural" status (Kreyling et al., 2021). This is why understanding the thresholds of WTD that induce these changes and their shift when peatland status is altered can help assess the WTD level for rewetting purposes and how it has to be maintained.

CONCLUSIONS

The WTD change triggers shifts in vegetation dominance within peatlands. Consequently, the rewetting of these ecosystems needs to be predicted (in the context of GHG emission) considering the thresholds of WTD that cannot be surpassed to recover/maintain the "natural" vegetation. Not only do undisturbed peatlands present thresholds of WTDs that further induce the shift in vegetation, but drained and restored peatlands also have them. Drained peatlands show a peak in the dominance of trees-shrubs from annual average WTDs below -20 cm while it is below -18 cm for rewetted peatlands. This means that water table levels need to be monitored in drained peatlands to avoid further degradation and in rewetted peatlands to accomplish the restoration.

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SESSION II - THE RACE AGAINST POLLUTION

Ecosystem Services of Urban Wetlands

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INTRODUCTION

Urban wetlands are wetlands which are found in and around cities or their suburbs (Ramsar Convention, 2004). In principle, urban wetlands can be natural and constructed and also can be classified as permanent or temporary. Due to the effect of urbanization, urban wetlands have become unconnected and fragmented. They have become patchy and distributed in different areas. This habitat fragmentation in urban wetlands has led to a decrease of ecosystem services (Alikhani et al., 2021). Nowadays, the constructed wetlands increase the importance of urban wetlands by restoring original ecosystem services.

Wetland ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from wetlands (Costanza et al., 1997). MEA (2005) distinguishes four major areas of ecosystem services, namely Provisioning (food production, water storage and retention for domestic, industrial and agricultural use, fiber and fuel, extraction of medicinal materials from biota), Regulating (climate, flood and erosion regulation, water purification), Cultural (spiritual and inspirational, recreational, aesthetic, educational) and Supporting (soil formation, nutrient cycling, biodiversity, habitat provision).

PROVISIONING SERVICES

In general, the most important ecosystem service derived from wetlands in this category is probably production of food. This service is quite often neglected when urban wetlands are evaluated but may be very extensive. The most common product of urban wetlands is rice which is grown commonly in urban wetlands in Asia, but good examples can also be found in Europe as well. Another common service from urban wetlands is production of fish. A typical example of such service can be the Czech Republic where fishponds were built in many cities and villages as early as during 14th to16th centuries.

Water storage and retention with further reuse usually applies in urban wetlands for stormwater runoff. The process is also known as “water harvesting” and it is believed that this term was invented in Australia where most of the country suffers from water shortage. The retained water is mostly used in urban areas for irrigation of public green spaces.

REGULATING SERVICES

Urban wetlands help to mitigate climate change in the sense that they cool down the areas surrounding the wetlands (Hesslerová et al., 2022). Bounding solar energy by water evapotranspiration, i.e., cooling, in places with surplus energy and releasing solar energy in cold areas where water condensates is the principle how natural air-conditioning operated by water and plants works (Pokorný, 2019).

(Waste)water purification is performed mostly by constructed wetlands. There are numerous examples of the use of such wetlands around the world for treatment municipal wastewater, stormwater overflows, water bodies and stormwater runoff from various areas such as streets, parking lots, airports or nurseries (Vymazal and Kröpfelová, 2008). The stormwater runoff wetlands can be considered a part of the concept of Sustainable Urban Drainage Systems (García and Santamarta, 2022).

Urban wetlands are also important in preventing or mitigating flood events. It has recently been reported how flood impact was intensified because local wetlands had been destroyed during development in the Beijing-Tianjin-Hebei metropolitan area in China (Mao et al., 2023).

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CULTURAL AND SUPPORTING SERVICES

The frequency of the urban wetland park visit has greatly increased with the improvement of people´s leisure awareness and the need of leisure diversification. Therefore, urban wetlands, as a part of overall urban planning, need to combine wetland ecosystem services and landscape recreation activities to improve the natural eco-efficiency of wetlands and the value of urban social functions (Zhang et al., 2022).

According to the survey carried out in the United Kingdom (Andrews and Russo, 2022), people perceive urban wetlands mainly as source of biodiversity, flood control, water quality improvement and to lower extend as sites for exercising, social interactions, photography and natural play space (Andrews and Russo, 2022).

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SESSION II - THE RACE AGAINST POLLUTION

Subsurface flow constructed wetlands for the treatment of agricultural drainage: over five years of operation

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INTRODUCTION

Natural wetlands are able to retain nitrogen from freshwaters, which was reported as early as in the 1970s (Mitsch et al., 1979). Constructed wetlands (CWs) were proposed as a suitable tool for removal of nitrogen (mostly nitrates) from agricultural drainage in the early 1990s (Mitsch, 1992). Nowadays, the CWs are commonly used for this purpose globally. The predominantly applied type of CWs used for that purpose are systems with free water surface. However, CWs with subsurface flow can also provide favourable conditions for the removal of nitrogen with microbial denitrification as the underlying mechanism. Due to carbon deficiency of agricultural drainage water these types of CWs need to be supported with additional carbon sources as, for example, woodchips. The presence of nitrogen (and sometimes phosphorus) in not the only challenge for agricultural drainage treatment. The contaminants that are highly relevant for that type of wastewater are pesticides. The occurrence and persistence of pesticides and their metabolites in the aquatic environment is a major problem in the Czech Republic and worldwide (Hvězdová et al. 2018). One of the main routes for the transfer of pesticide-associated pollution into the aquatic environment is agricultural drainage waters, surface runoff and improper disposal of pesticide wastes (e.g. from spray equipment cleaning) (Damalas et al., 2008). Denitrifying CWs are a cost-effective solution for treating highly variable tile drainage and runoff flows by reducing nutrients (mostly nitrate) (Vymazal et al., 2020), but the prevalence of anoxic conditions might be not as favourable for the degradation of pesticides and their metabolites as aerobic conditions. The goal of this research was to evaluate the efficiency of pilot-scale CW systems treating agricultural drainage for the removal of total nitrogen (TN) and pesticides over a period of five years and to propose methods for the improvement of their efficiency.

METHODS

This study included two complimentary systems (Fig. 1): a pilot-scale system treating agricultural drainage water and a small-scale column system treating pond water spiked with nitrates and pesticides or their metabolites.

a) b)

Fig. 1. CW systems used in the research: a) pilot-scale system; b) small-scale system

System 1 – pilot-scale CWs

In 2018, three experimental horizontal-flow CWs were constructed to treat tile drainage from 15.73 ha watershed in the Czech Republic. The area of drained fields within the watershed is 9.85 ha. The experimental site is situated about 100 km southeast from Prague in the watershed of the drinking water reservoir Švihov, the major supplier of drinking water for Prague. The wetlands have surface areas of 79 m^2 (M1), 90 m^2 (M2) and 98 m^2 (M3) and are planted with a combination of reed canarygrass (*Phalaris arundinacea*) and sweet mannagrass (*Glyceria maxima*) planted in parallel bands. The substrate in the first two CWs is crushed rock (4–8 mm) mixed with air-dried birch woodchips with the volume ratio of 10:1. In the first wetland (M1), the water level is kept 10 cm above the surface, in the second wetland (M2), the water is kept 5 cm below the surface. The third wetland (M3) has a 20 cm layer of birch woodchips on top of gravel (4–8 mm) and water level is kept about 10 cm above the surface to make sure the woodchips are flooded. All wetlands are 1.0 m deep and lined with 1 mm plastic liner (Vymazal et al., 2020).

System 2 – small-scale CWs

The potential improvement in the removal of TN and pesticides in the CWs were tested in small-scale systems mimicking the conditions in the pilot-scale CWs and enhanced systems with water-unsaturated filtering bed (aerobic) or with reactive amendments as manganese oxides and steel chips.

RESULTS and DISCUSSION

System 1 – pilot-scale CWs

The median concentration of TN (mostly nitrates) and total organic carbon in the study period were 14.3 mg/L and 5.1 mg/L, respectively. This C/N ratio was too low to support microbial denitrification therefore woodchips were used as an external carbon source.

In the system 1, The overall concentration-based removal of TN in the period December 2018 - March 2024 was 21%, 25% and 31%, for M1, M2 and M3, respectively. The removal in the arbitrarily assumed cold period (November-May) was 16%, 19% and 26%, for M1, M2 and M3, respectively. The removal in arbitrarily assumed warm period (June-September) was invariably higher and was equal to 50%, 53% and 66% for M1, M2 and M3, respectively. However, the difference between the systems were found not to be statistically significant ($p \geq 0.05$). The increased efficiency in the warm period is associated with greater activity of denitrifying organisms. The time-dependent removal has slightly decreasing trend with at the same time decreasing influent concentration of TN, suggesting deteriorating treatment efficiency. One of the causal effects can be depletion of the pool of organic carbon in the woodchips, which is crucial to support denitrification.

Over the study period 52 pesticide compounds, either parent compounds or their metabolites were found in the influent of the system. Out of those, 21 substances were detected with considerable frequency and only five were parent compounds. The overall removal of pesticides was negligible (1%), which was probably associated with long half-life degradation time (DT_{50}) under anoxic conditions. The negative removal (release from CWs) can result from flow fluctuations and retransformation or desorption from suspended particles in the CWs.

System 2 – small-scale CWs

The presence of steel chips in water-saturated CWs considerably improved the removal of several parent pesticides compared with the control system (with sand) and the standard system with woodchips. The CWs with steel chips also provided complete removal of TN and were more resistant to seasonal temperature decline. The application of steel chips decreased the toxicity of the wastewater, however, the pesticides were not fully mineralized, but only transformed to their derivatives. The application of manganese oxides, which are commonly used as oxidants and sorbents in water treatment plants, was found to improve the elimination of metabolites of commonly applied herbicide metazachlor only slightly. Moreover, the use of water-unsaturated

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CWs as an post-treatment step after denitrifying CWs did not provide considerable removal of pesticides nor their metabolites.

CONCLUSIONS

The horizontal-flow CWs have been found to be efficient for the removal of TN with seasonal decline in the November-May period. The application mode of woodchips in CWs, either mixed within or placed on top of the filtering bed, does not considerably affect the elimination of TN. From the operation and maintenance perspective the application or replacement of woodchips on top of a CW would be much easier and more economically feasible than excavating the entire filtering media. Pesticides and their metabolites create a considerable challenge for the treatment in CWs. Horizontal-flow CWs are not able to efficiently remove these substances. Some amendments like steel chips can overcome this limitation at least for the parent compounds and at the same time provide improved removal of TN. The abatement of pesticide metabolites, however, remains a challenge that must be addressed to ensure the safety use of water resources.

ACKNOWLEDGEMENTS
The authors acknowledge the project TM03000051, Technology Agency of the Czech Republic.

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Floating ferns for wetland restoration? Lessons learnt from four years of Azolla cultivation on former agricultural soils

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INTRODUCTION

The restoration and novel creation of wetlands is crucial as they provide myriad ecosystem services including carbon sequestration. Degraded wetlands have often known agricultural use, resulting in a substantial nutrient legacy, especially of phosphorus (P). Subsequent rewetting of these former agricultural soils typically leads to water quality issues, low biodiversity and high methane emissions. To overcome these challenges in a novel, cost-effective way, Azolla filiculoides (water fern) could be cultivated to simultaneously extract P, sequester carbon, and provide a commercial product. Azolla is excellent at accumulating P due to its nitrogen fixating capacity and high growth rate.

METHODS

To test this approach, we cultivated Azolla on former agricultural peat and mineral soils in several field and mesocosm trials. We measured soil, water, and plant nutrient dynamics, and methane emissions.

RESULTS and DISCUSSION

We found that Azolla cultivation is only feasible on soils with a high P mobilisation potential under oxic conditions, as Azolla cover did not reduce surface water oxygen concentrations as anticipated. Only after prolonged (>1 year) cultivation, oxygen levels dropped, presumably due to organic matter accumulation and subsequent decomposition. On suitable soils, P extraction rates up to 122 kg ha^{-1} yr^{-1} were measured, while surface water P concentrations remained low. Methane emissions (diffusion and ebullition) were highly dependent on time frame, season, and development of other macrophytes and algae.

CONCLUSIONS

We conclude that cultivating Azolla shows potential in the transition from agriculture to nature, while recovering P from former agricultural soils. Remaining challenges include pest control, product development, and technologies for large-scale implementation.

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Historical soil compaction impairs biogeochemical cycling in restored tidal marshes through reduced groundwater dynamics

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INTRODUCTION

Tidal marshes are highly valued for the delivery of ecosystem services, such as the regulation of water quality through removal of nitrogen and retention of phosphorus. Soil-groundwater interactions in tidal marshes play a crucial role in this water quality regulation service.

In the past centuries, natural tidal marsh area drastically declined throughout the world, due to large scale land reclamation. Nowadays, an increasing number of tidal marshes are restored on formerly reclaimed agricultural land to regain the delivery of their ecosystem services. However, the former agricultural land use is often paired with negative ecological effects. The excavation of artificial ditches caused excessive soil drainage, resulting in mineralization of organic matter, soil consolidation and reduction of soil porosity (Spencer et al., 2017), which leads to reduced groundwater level fluctuations in restored tidal marshes as compared to natural tidal marshes (Van Putte et al., 2020).

In this study, we link measured nutrient concentration profiles to soil aeration patterns governed by groundwater dynamics. Furthermore, we determine at which depth along the soil profile the main form of dissolved nitrogen (nitrate vs. ammonium) occurs in the porewater and where phosphate is retained. These insights are helpful in the design of new tidal marsh restoration projects to assess the effects of certain design measures (e.g. creek excavation or soil amendments) that alter soil aeration patterns, on biogeochemical cycling.

METHODS

We studied soil hydraulic properties and groundwater dynamics in function of depth and distance from the nearest tidal creek on several transects in a natural (De Notelaer) and a restored (Lippenbroek) freshwater tidal marsh in the Scheldt estuary, Belgium. We measured monthly porewater nutrient concentrations over a depth profile during one year using porewater equilibrators (peepers). The principle of this peeper is that dissolved nutrients in the soil pore water surrounding the peeper are exchanged through the membrane until the water in the peeper compartments is in osmotic equilibrium with the surrounding soil pore water. We then linked these measured concentrations to the calculated soil saturation index (SSI, the proportion of time the soil is saturated at a certain depth).

RESULTS and DISCUSSION

Depth profiles of nutrient concentrations are related to the depth of groundwater level fluctuations and soil aeration. In zones with a high SSI, such as the marsh interior, and especially in the restored marsh, nitrogen accumulates in the porewater in the form of ammonium. NH_4 concentrations are positively correlated with the SSI ($\rho = 0.32$, $p < 0.001$). Here, anoxic conditions prevent nitrification and promote ammonification. In the compact agricultural soil, which has a lower organic matter content, ammonium stays in solution. In the upper zones where the SSI is lower, nitrogen is mainly present as NO_3. Hence, nitrate concentrations are negatively correlated to the SSI ($\rho = -0.21$, $p < 0.001$). Porewater NO_3 concentrations were generally higher closer to the creek, where the residence time of the porewater is shorter resulting in porewater nitrate concentrations that are more similar to estuarine water nitrate concentrations. In the marsh interior, where the residence time is longer, nitrate concentrations are lower as NO_3 is removed by denitrification and the porewater is less often refreshed.

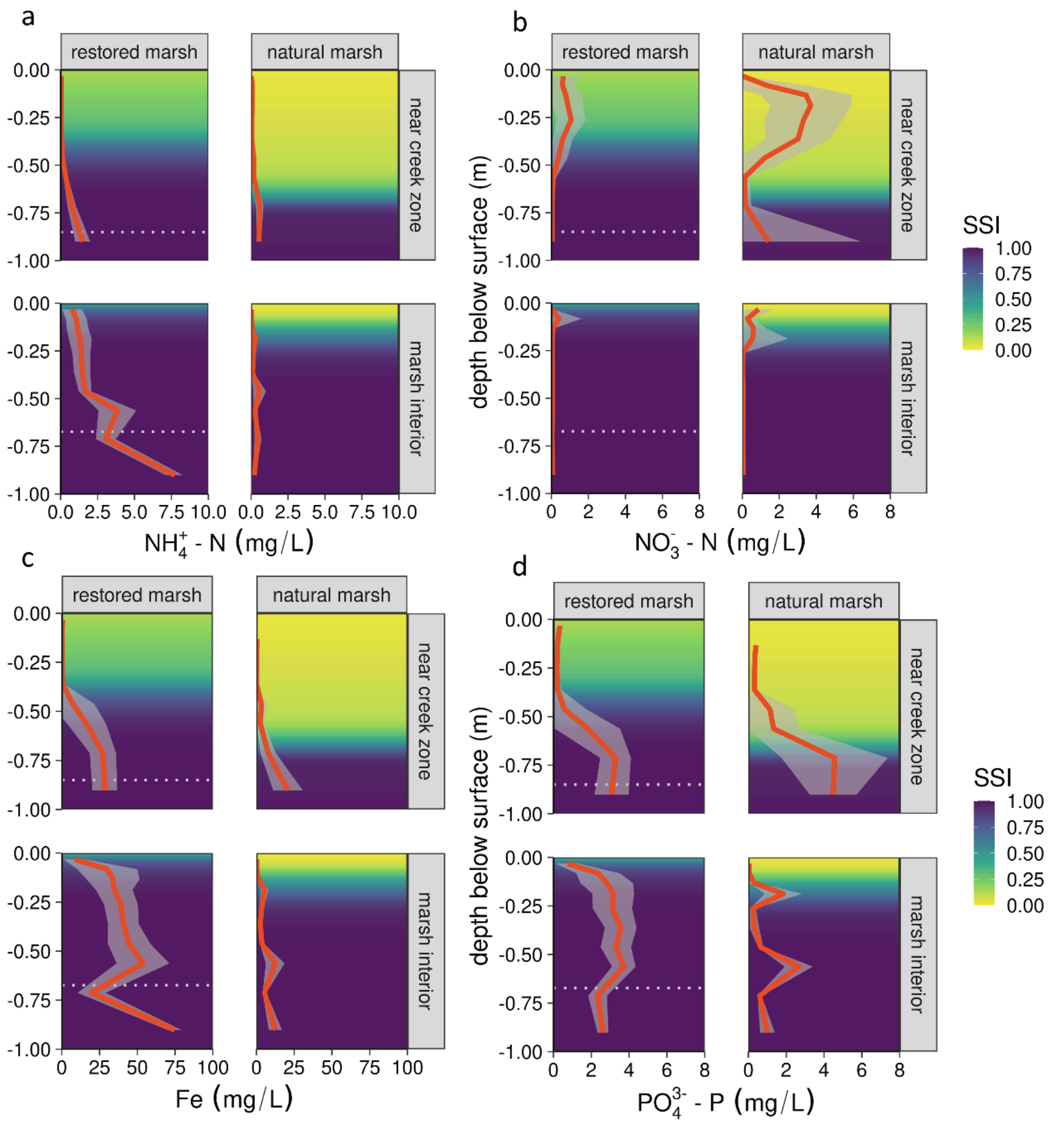

Fig. 1. Average measured porewater concentrations in the restored marsh and the natural marsh of (a) ammonium, (b) nitrate, (c) dissolved iron and (d) phosphate. Grey ribbons represent the standard deviation on the measurements. Background colors indicate the soil saturation index (SSI). Horizontal dotted lines represent the transition between the tidally deposited sediment layer and the underlying compact relict agricultural soil in the restored marsh. Near creek zone and marsh interior are 1 m and 22 m from the creek edge, respectively.

Since coupled nitrification – denitrification is enhanced by fluctuation of groundwater levels and consequent alternating aerobic and anaerobic conditions, impaired removal of nitrogen from the estuarine water by the marsh soil is expected where groundwater dynamics are reduced.

The concentration of dissolved phosphate is strongly correlated with the SSI ($\rho = 0.43$, $p < 0.001$). The same applies to the concentration of dissolved iron ($\rho = 0.44$, $p < 0.001$). Both dissolved phosphate and dissolved iron concentrations are higher in anoxic zones. In well aerated zones, dissolved ferrous compounds oxidize and form iron oxyhydroxides that precipitate from solution, to which phosphate can sorb. In this way, iron oxidation through soil aeration controls phosphorus solubility. Dissolved phosphate moves from the more anoxic marsh interior towards the well aerated creek zone through porewater advection. Here, the dissolved phosphate sorbs to iron oxides resulting in decreased phosphate concentrations in the groundwater seeping from the creek banks (Chambers and Odum, 1990; Megonigal and Neubauer, 2019), forming an 'iron curtain' that traps dissolved phosphorus. Since the compact subsoil in the restored marsh reduces the extent of the aerated zone, this trapping of phosphate ions is expected to be impaired as less sorption sites for phosphate are available.

CONCLUSIONS

Where the presence of a historically compacted subsoil hampers groundwater drainage, nitrification is impaired and dissolved nitrogen is mainly present as ammonium. In well drained zones, such as near creeks in the natural tidal marsh, denitrification is impaired and high nitrate concentrations build up, suggesting the benefit of the co-existence of both saturated and unsaturated zones in the marsh soil to maximize nitrogen removal. Furthermore, we found the presence of dissolved phosphate to be highly positively correlated to the SSI, with very high concentrations in the compacted soil in the restored marsh, implying the importance of soil aeration for improved P retention. In general, we conclude that soil aeration patterns and associated biogeochemical cycling is highly depending on pre-restoration land use and post-restoration subsurface hydrology.

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Characterizing the Beneficial Uses of Arcata Marsh Constructed Wetland System and Wildlife Sanctuary

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INTRODUCTION

The Arcata Marsh Wastewater Treatment Plant and Wildlife Sanctuary have supported the community of Arcata California with a population of 20 thousand, since the 1980s. Not only has it served as the city's primary wastewater treatment facility, designed to treat 2.3 million gallons of wastewater per day, it has also provided a variety of additional beneficial uses including habitat creation, recreation, education, research, and many more.

The site consists of primary and secondary treatment, followed by two large oxidation ponds, six densely vegetated wetlands, and three open water vegetated enhancement wetlands. The effluent is disinfected and finally discharged into Humboldt Bay, which is the major estuary between San Francisco Bay of Northern California and Puget Sound of Washington (Schlosser & Eicher, 2012). Humboldt Bay is known for its rich marine habitats and shellfish production, acting as the largest producer of oysters in California (Archer, 2020).

While over 90% of wetland habitats in Humboldt County have disappeared in the past century due to roadwork, construction, and agricultural development, the Arcata Marsh remains healthy and resilient to this day (USFWS, 2023). Its success as a *constructed* natural wetland treatment system has garnered public recognition and is the pride and joy of the city of Arcata and its citizens. Due to the nutrient-rich wastewater feeding into the system, the wetland vegetation are luscious and rich, providing crucial habitats for waterfowl, amphibians, mammals, macroinvertebrates, and all other sorts of wildlife.

Arcata Marsh is open to the public where birdwatchers and nature-lovers enjoy and take in the natural scenery, and its close ties with the local Humboldt State University (now Cal Poly Humboldt) has provided educational and research opportunities to many students and faculty alike. The Friends of Arcata Marsh (FOAM), an NPO based in Arcata, strives to educate the public on the functions and role of Arcata Marsh and wetland treatment systems, hosting special events such as Godwit Days (Godwitdays, 2024), lectures, and nature walks. Furthermore, students and professionals outside the area have gathered to learn more about the success story of Arcata Marsh.

While the Arcata Marsh boasts all these beneficial uses, they have never been fully characterized or quantified since its inception. With a large system expansion going underway, this project aims to characterize and quantify these beneficial uses once and for all.

METHODS

The beneficial uses of the Arcata Marsh have been identified and methods to characterize and quantify them have been developed. Some of these beneficial uses include: 1) Water quality enhancement, 2) freshwater habitat creation, 3) education and research, 4) recreation, health, and sustainability, and 5) buffering during large storm events.

<u>Water quality enhancement</u>: Water quality results have been recorded since start-up, and the performance of each part of the wetland treatment system can be assessed and compared annually. This will show us a side-by-side comparison of the system at an earlier stage versus a later stage, after 40 years of operation. The effluent quality will be compared to the effluent

standards of United States EPA's National Pollutant Discharge Elimination System (NPDES) permits for Arcata's WWTP.

Freshwater habitat creation: The City of Arcata have been conducting seasonal rapid assessments on species type and population size for the past ten years. This data can be used to determine if the Arcata Marsh provides a regular habitat for these species, and whether it hosts a "healthy" ecosystem/habitat. Furthermore, this habitat data can be compared with the water quality for those seasons to determine a correlation between habitat and water quality.

Education and research: Student projects, research projects, lectures, and degrees earned, are directly influenced by the Arcata Marsh. These project contributions have also led to process improvements, which can be quantified via percent reduction changes over the years.

Recreation, health, and sustainability: The City of Arcata and the Friends of Arcata Marsh (FOAM) have recorded the number of walk-ins and paid activities done at Arcata Marsh. This can be used to determine the amount of foot-traffic into the system. Furthermore, surveys will be conducted to get an understanding of the city's perception of the marsh. These questions will identify 1) what the citizens think of the marsh, 2) what they use it for, and 3) are they aware of its functions.

Buffering during large storm events: Wetland inflows and water treatment performances will be investigated during large precipitation events to see if the system is still achieving adequate water treatment compared to non-storm events. Sewage spillage/overflow violations will be investigated at the Arcata Marsh and a nearby conventional WWTP and compared.

RESULTS and DISCUSSION

Historical water quality trends from the inlet to outlet of the treatment train show that the current system is performing at the same level, if not better than the level of treatment in earlier years. Figures 1 and 2 show the historical trend of BOD_5 and TSS from inlet to outlet of the system with the following constraints: high temperature, low flow, and high influent load.

Figure 3 shows the change in percent removal of BOD_5 achieved by the whole system from the inlet to the outlet. This figure demonstrates that precent removal for BOD_5 has improved with time.

Figure 4 shows a distribution of total number of birds observed in the three Enhancement Wetlands during the Spring and Fall seasons from the years 2013 to 2022. This bar graph demonstrates that while populations may decrease in certain years, they will make a comeback in the following years, which showcases how dynamic the system is. Nonetheless, the presence of birds in every year proves the health of the ecosystem.

The recreational value, or the public usage of the Arcata Marsh Wildlife Sanctuary and Interpretive Centers is shown in Figure 5. This is expressed via the total number of walk-ins, paid lectures, and special events recorded by the Friends of Arcata Marsh (FOAM) from the years 2013 to 2022. While there is a significant decline during 2020 and 2021, which reflects the lockdowns occurring during the COVID-19 pandemic, the following year shows a rebound.

Figures 6 and 7 show the Educational Value of Arcata Marsh by publication discipline and publication type, respectively. Publications, citations, and references made on Arcata Marsh, as well as technical memos produced by the student researchers of Arcata Marsh Research Institute are expressed on these bar graphs. The figures show that the number of publications and studies done on the Marsh are increasing, which demonstrate that the educational influence of Arcata Marsh is spreading.

Survey results outlining the different recreational uses of the marsh, and buffering during large storm events are still in process.

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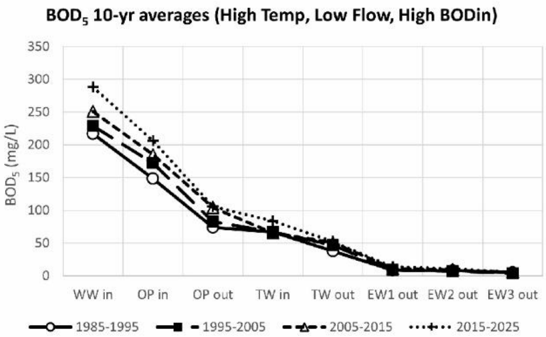

Fig. 1. BOD_5 change from inlet to outlet (High Temp, Low Flow, High BODin)

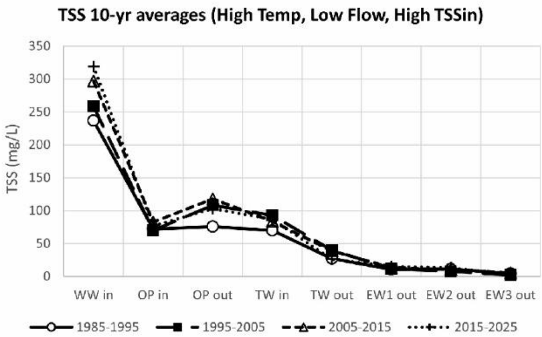

Fig. 2. TSS change from inlet to outlet (High Temp, Low Flow, High TSSin)

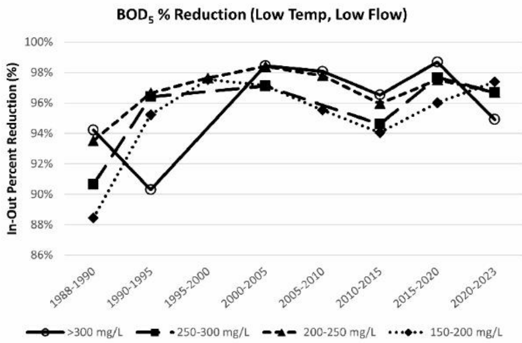

Fig. 3. Inlet to Outlet BOD_5 percent reduction from 1988 to present (Low Temp, Low Flow)

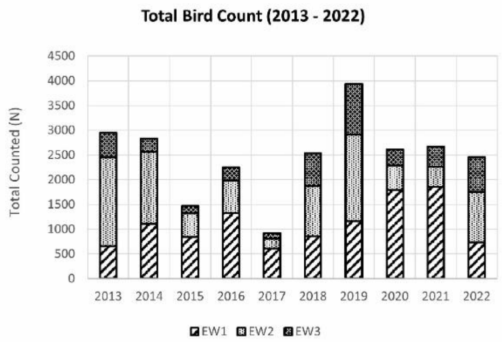

Fig. 4. Total Bird Count (2013 – 2022)

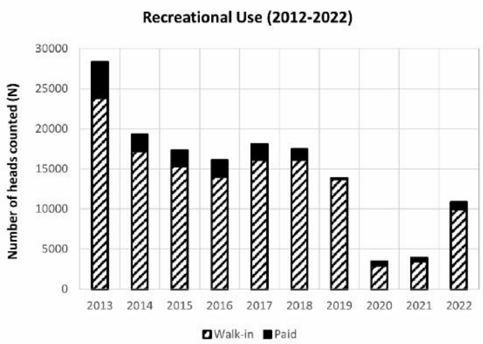

Fig. 5. Recreational Use (2012 – 2022)

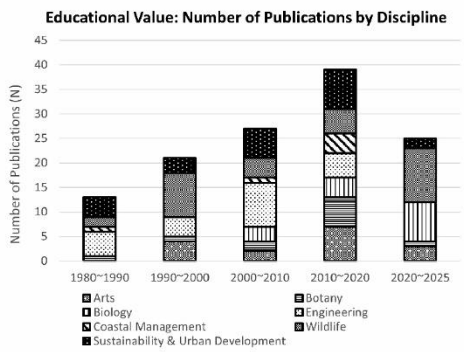

Fig. 6. Educational Value by Discipline (1980 – present)

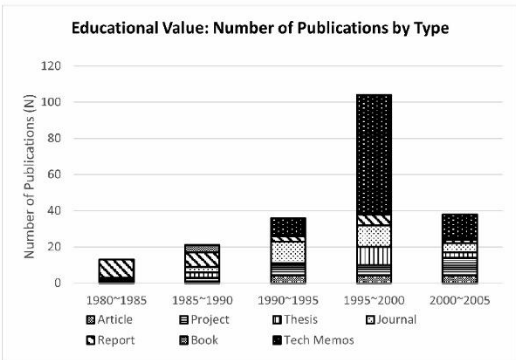

Fig. 7. Educational Value by Publication Type (1980 – present)

CONCLUSIONS

The results and supporting figures prove that 1) the system is achieving adequate water treatment, 2) the system provides education and research opportunities that lead to its own process improvements, 3) the system provides a healthy habitat for a variety of wildlife, and 4) the system is a hotspot for visitors for various recreational activities. All these points are important for the longevity of the Arcata Marsh – wastewater “enhancement” not only enhances the water quality, but also enhances the surrounding habitats as well. These provide a plethora of research opportunities for many disciplines, which raises the awareness of the functions of Arcata Marsh which extend past the boundaries of Arcata City. Finally, the recreational activities the marsh provides, bolster the physical and mental health of the city.

ACKNOWLEDGEMENTS

I would like to extend my gratitude to Dr. Robert Gearheart for the inspiration for the project, as well as his strong guidance on this project. I would also like to thank the City of Arcata WWTP as well as Friends of Arcata Marsh (FOAM) for their data contributions. Finally, a heartfelt thank you to Dr. Tesfayohanes Yacob and Dr. Christa Meingast for their supervision and input, as well as the student researchers of Arcata Marsh Research Institute (Fiona Connors, Elise Culbertson, Angel Cortez-Ramirez, and Zander Leigh) for their support.

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Simultaneous pesticide dynamics in surface water and subsurface shallow groundwater in depressional wetlands of north-east Germany

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INTRODUCTION

Wetland water quality in agricultural landscapes is expected to reflect surrounding agricultural activities on the local scale. This especially applies to field-specific application of pesticides, which are expected to be mainly transported into aquatic systems by surface runoff and local-scale wind-drift. However, there is evidence of a number of pesticides with ubiquitous occurrence in different kinds of aquatic settings, questioning current theories on their transport and fate. This current study from north-eastern Germany presents monitoring results of pesticides in kettle holes at agricultural fields and adjacent shallow groundwater.

METHODS

In the period from February 2020 to the present day, a total of seven kettle holes in north-eastern Germany (Brandenburg, Uckermark region) were analyzed monthly (depending on water level) for residues of pesticide active substances. Near-surface shallow groundwater was sampled at a depth of 1.5 to 2.9 m (depending on the installation depth of the measuring point) close to the kettle hole. The sampled waterbodies are located in the young moraine landscape of the northeastern German lowlands, a region containing >150 000 kettle holes that cover up to 5% of the agricultural area (Kalettka and Rudat 2006). Kettle holes are small, isolated, depressional wetlands formed during the last glacial period, with a high potential for biological species diversity (Kalettka and Rudat 2006). The spectrum of active substances examined followed German guidelines for monitoring small water bodies. In addition, the residues of 14 active substances no longer approved for use (atrazine, bromacil, dimefuron, dinoterb, diuron, ethidimuron, ethofumesate, fenuron, flusilazole, hexazinone, oxadixyl, prometryn, propazine, trifluralin) were analyzed.

All pesticides in the water samples except pyrethroids were quantified by liquid chromatography mass spectrometry in electrospray ionization mode (LC-ESI-MS/MS) using the internal standard method after solid phase extraction (Chromabond HR-P, Macherey-Nagel, Germany, 50–100 µm particle size, 3 mL column volume, 200 mg filling quantity). We used a 1290 Infinity II LC system (Agilent, USA) coupled to a QTRAP 6500 + mass spectrometer (SCIEX, USA) and the previously mentioned system (LC-ESI-MS/MS). Reference standards in solvent were used. For pyrethroids, the active substances in the water sample were concentrated by liquid–liquid extraction and then analyzed by gas chromatography–mass spectrometry (GC-MS) using a Trace GC Ultra coupled to a TSQ Quantum GC XLS mass spectrometer (both from Thermo Electron Corporation, USA). The recovery of pesticides was in the range of 0.0010–0.50 µg/L. The limits of quantification (LOQ) were active substance specific ranging from 0.001 to 0.050 µg/L. The limits of detection (LOD) were half the LOQs.

RESULTS and DISCUSSION

The results show that there is a high risk from pesticide inputs over the course of the year, particularly for the groups of green algae and aquatic macrophytes (Fig. 1).

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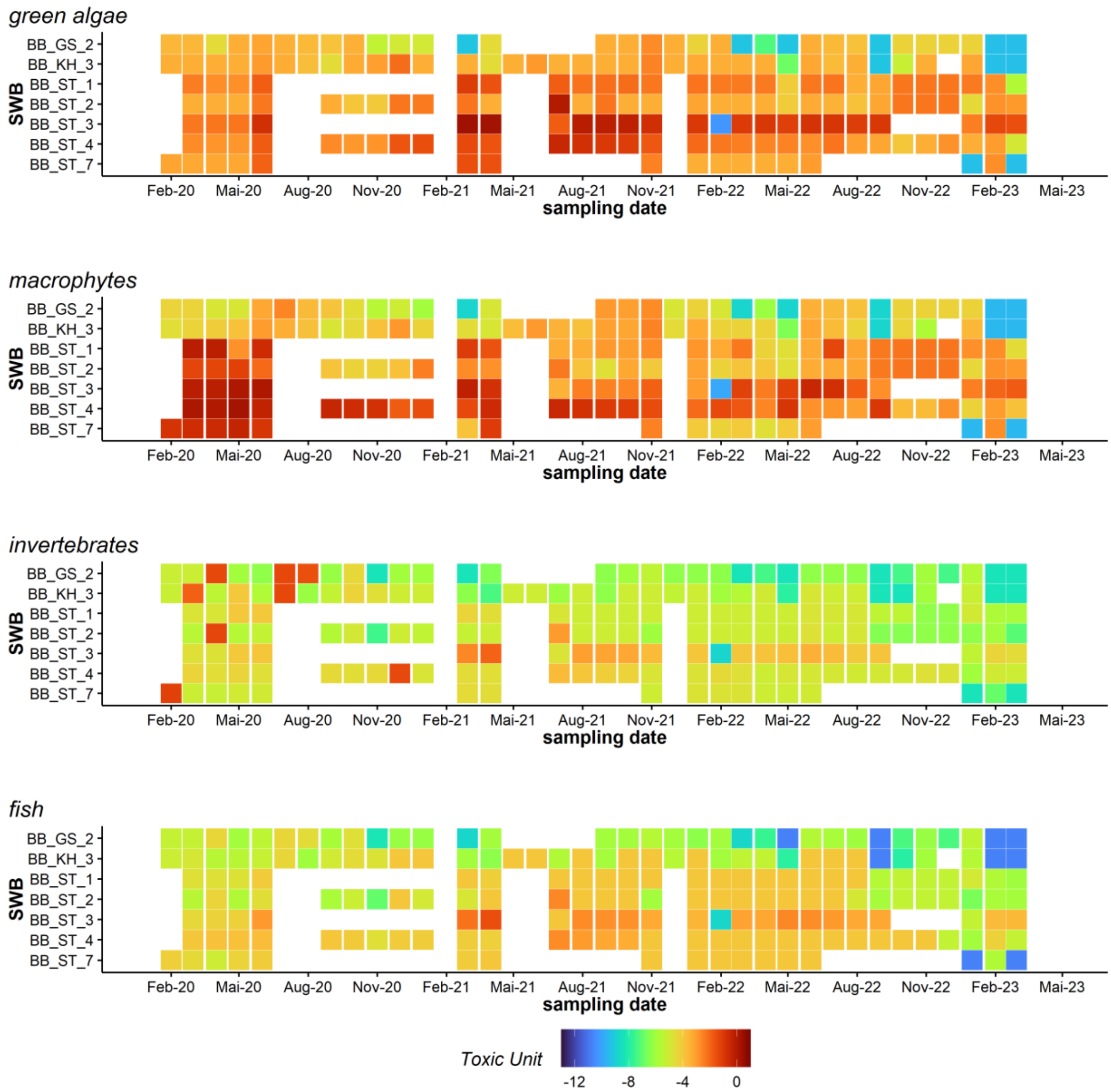

Fig. 1. Course of maximum Toxic Units (logarithmic TUmax) for green algae, aquatic plants, invertebrates and fish in seven small standing water bodies (SWB) over three years of sampling.

The toxicities determined for individual periods and water bodies reach values of logTUmax > 0, which are to be classified as extremely alarming. These high toxicities are mainly caused by five herbicides (diflufenican, flufenacet, foramsulfuron, nicosulfuron, terbuthylazine). A logTUmax > 0 corresponds to an exceedance of the half-maximum effect concentration (EC50) from the standard test trials as part of the plant protection product approval, which however occur here under field conditions.

About 40% of the active substances analyzed occur both in surface water and in shallow groundwater (Fig. 2). The results reveal simultaneous dynamics between subsurface and surface water with respect to both, occurrence and concentrations of a number of substances (Fig. 3). These dynamics are not restricted to individual locations but are found on a larger scale with a maximum distance of 12 km between the study sites. We suspect subsurface hydrology to be a driver of similar patterns in surface water and shallow groundwater.

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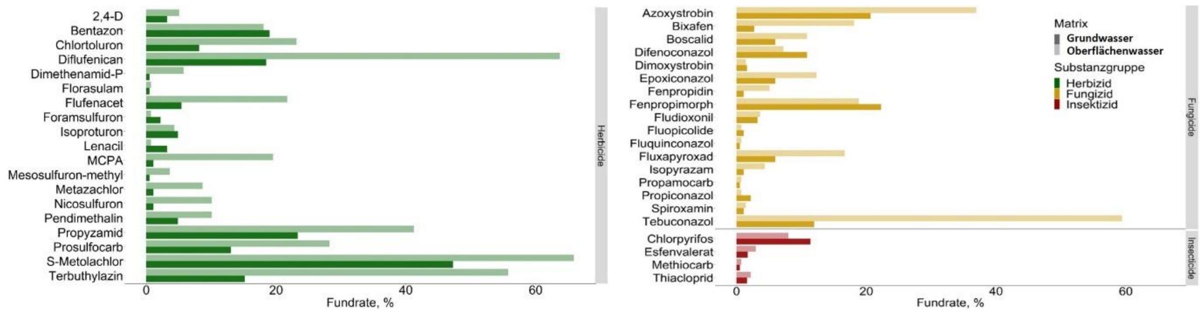

Fig. 2. Detection rate ("Fundrate, %") of herbicides, fungicides and insecticides in surface water ("Oberflächenwasser", light bars) and shallow groundwater ("Grundwasser", dark bars) over the sampling period.

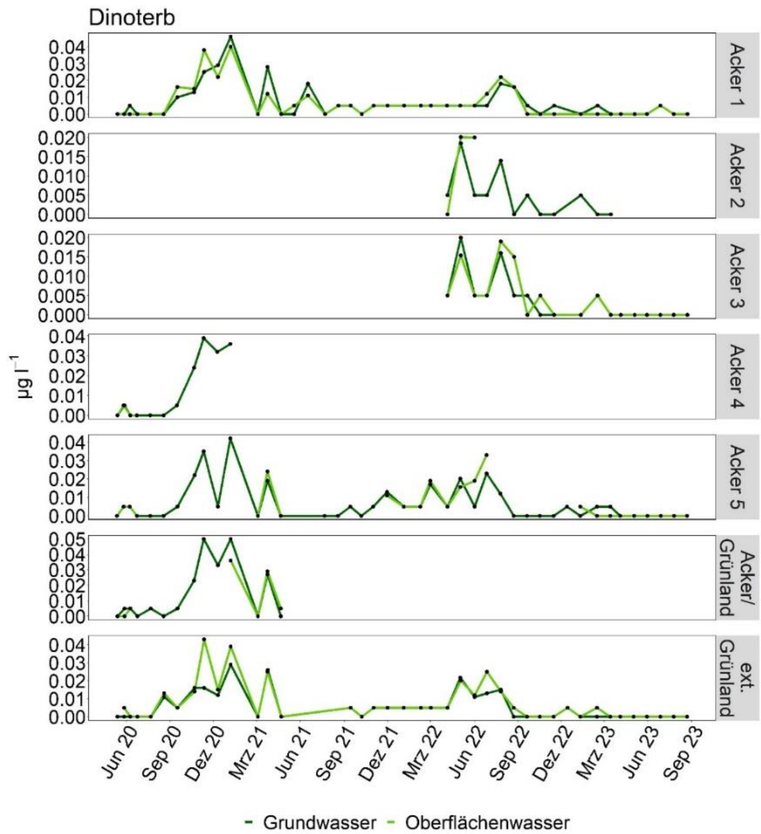

Fig. 3. Pattern of ubiquitous pollution through long-term continuous inputs, exemplified by the occurrence of dinoterb (herbicide/rodenticide, banned in the EU since 1997) into surface water ("Oberflächenwasser", light green) and shallow groundwater ("Grundwasser", dark green) for seven small standing water bodies.

ACKNOWLEDGEMENTS

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SESSION II - THE RACE AGAINST POLLUTION

A Citizen Science and Engagement Approach to Tackle Plastic Pollution in England

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INTRODUCTION

River pollution is a highly concerning problem at the local, regional, national, and global level. Plastic waste and litter have never been so prominently recognized challenges that humans need to overcome to preserve terrestrial and aquatic ecosystems and human health (van Emmerik and Schwarz, 2020). The Plastic Free Mersey (1) and Plastics Action (2) projects are highly collaborative initiatives to stem plastic pollution in England. The former brings together businesses in the plastics supply chain with NGOs working with volunteers, communities, and academics, while the latter connects local groups with regional partners, such as Rivers Trusts, and national NGOs, such as Keep Britain Tidy to try to upscale river (and beach) clean-ups. These projects are complementary in addressing plastic pollution with an all-hands-on-deck approach from the individual and community / local level to the regional and national level.

METHODS

Our general goal to reduce plastic pollution and augment public awareness of how to curb and prevent this widespread problem has been pursued through citizen science, surveys, workshops, and public events in the Mersey and other catchments. While the Mersey project has focused on the relative catchment, Plastics Action has reached out to the Mersey and another three catchments / regions: the Tyne, Anglian region, and River Kennet sub-catchment of the Thames. One of our events involved Liverpool City Region's Mayor Steve Rotheram and the former Mayor of Liverpool Joanne Anderson; both leaders endorsed the Plastic Free Mersey project and learned about our findings in Knowsley, eastern Liverpool. (1) More than 20 trained citizen science volunteers have collected information on litter abundance (including fragments) and distribution across the catchment. We organized several engagement events to publicize the project and its findings, including a logo competition in which 40 students drew logos of the project, four of which were used by a graphic designer to create our project logo. (2) The Plastics Action project used online surveys, 17 volunteer interviews, two workshops, and several Steering Group meetings with volunteers and stakeholders to gather information on successes, challenges, and lessons learnt on the part of local river clean-up groups, often connected with one of our regional partners (Tyne Rivers Trust, Mersey Rivers Trust, RiverCare Beach Care, and Action for the River Kennet). Over 30 volunteers have been surveyed and/or interviewed. A Roadmap is being finalized to scale up river clean-up group activities, which includes advice on estimating costs for local litter pick groups. We also ran a national conference attended by >60 people (see Figure 3), where Thames21, partners, volunteers, and stakeholders including academics and a Member of Parliament of a London constituency presented and discussed their respective work on clean-up activities and policies on littering prevention.

RESULTS and DISCUSSION

(1) Plastic Free Mersey. About 20 volunteers have collected data on the amount and type of plastic and other litter items on riverbanks and on a few estuary sites. Over 7,000 litter items were recorded and safely removed from 12 rivers over two years and other volunteers participated in regular litter picks to remove larger amounts of litter from around rivers in the Mersey. Plastic food packaging, cigarette butts, plastic bags, and sanitary items (e.g. wet wipes) were the most prevalent items. The abundance of litter fragments was most often 1-9 and 10-99 fragments in the riverbank $60m^2$ sections surveyed; fragments were slightly more abundant on riverbanks than

at estuary sites (e.g.: on promenades overlooking the River Mersey estuary in the Liverpool area). In the sites surveyed thus far by our Mersey Rivers Trust volunteers, plastic litter accounted for >50% of the total litter found, which confirms what other citizen science studies have observed in sites around rivers and estuaries, as well as coasts (Winton et al. 2019). In Figure 1, the sites surveyed are shown; sites with bins (13 sites; ~80 data points) showed lower number of litter items than those without bins (7 sites; ~50 data points).

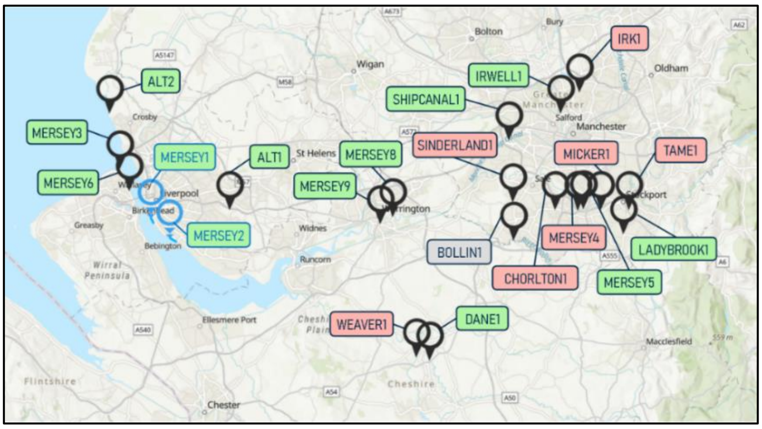

Fig.1. Map of data collection sites
(Green: sites with no bins; Pink: sites with bins; a bin was present but not close by at the Bollin1 site).

Where present, bins, were observed on promenades, near shops and retail parks, on adjacent roads, and in urban parks. The number of litter items found tended to be higher where no bins were present, but recent data is being analysed to ascertain whether the presence or absence of bins may be a direct cause of litter abundance. The number of fragments found in each 60m2 data collection area was most often either 1-9 or 10-99, which is not surprising based on other studies (Figure 2). This data on fragments represent both a demonstration of how litter breaks down over time and a reminder that further fragmentation is a key risk (i.e., microplastics threaten wildlife, ecosystems, and human beings) associated with plastics (as well as other litter materials).

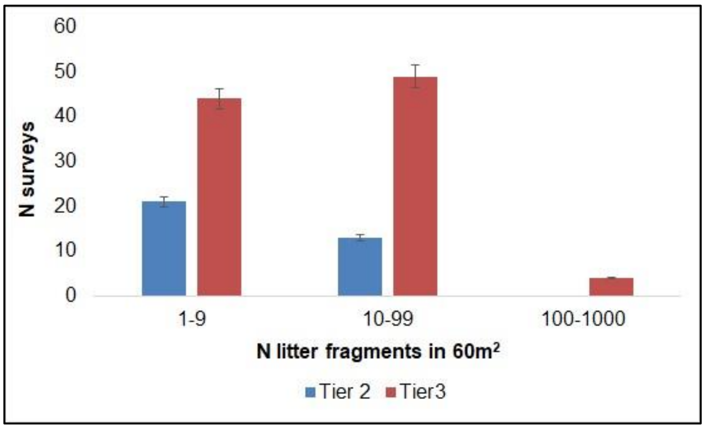

Fig. 2. Number of sites with different abundance of fragments in the 60m^2 survey sections on riverbanks in the Mersey catchment.

(2) Plastics Action. Volunteer surveys and workshops highlighted successful approaches and ongoing challenges when running local litter pick / river clean-up groups and events (see Figure 4). Online surveys, conducted in July 2022 by Thames21, have highlighted key data on group size, number and frequency of events, lessons learnt and challenges. Twenty-two volunteers responded to our 18 question online survey. Median values from surveys show that: the volunteer groups enlist 30 people, hold a monthly clean-up event, where just under 10 bags of litter are removed, with 50% of litter being plastics. Volunteers may get tired of *mopping the floor* by cleaning litter only for it to re-accumulate in river and terrestrial environments alike and are also

be looking forward to helping society as a whole to prevent littering and waste leakage from industry and other sources. Overall, enthusiasm and competency are high and heartening that these efforts will help change behaviours for good, helping people understand how important it is to not litter and refuse unnecessary items, reduce the use of plastic and other materials, reuse, recycle, recover, rethink, and repurpose (Marazzi et al., 2020). We are now finalizing a Roadmap to inform funding applications to best support the numerous local groups involved in actions to clean-up rivers and prevent plastic pollution moving forward. We will be seeking additional funding to empower these groups to do more and better towards cleaning up rivers and preventing further pollution.

Fig. 3. The Plastics Action national conference in London (30th November 2022).

Fig. 4. Volunteers at river clean-up events in East Anglia (left) and in Marlborough (right), southern England - connected to the Plastics Action project.

CONCLUSIONS

Combining citizen science and stakeholder and public engagement is both challenging and effective in tackling plastic pollution. The challenge is represented by working with industry, local authorities, other NGOs and community groups, alongside volunteers in order to understand litter distribution and pathways and ultimately reduce plastic and other litter in the river environments in England. The Plastic Free Mersey and Plastics Action projects have established and are maintaining valuable connections and working relationships with other Rivers Trusts and numerous volunteer groups working in their catchments, which are essential to enable knowledge sharing and mutual inspiration to clean-up rivers and prevent further pollution. Citizen science can also draw on collaboration with artists and teachers to stimulate meaningful change at the local and regional levels.

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ACKNOWLEDGEMENTS

We thank all of our >50 citizen science volunteers involved in both projects. Funding for the Plastic Free Mersey project from LyondellBasell, INOVYN, Peel NRE, British Plastic Federation and in-kind support from Plastics Europe and RECOUP is gratefully acknowledged. We thank the National Lottery Community Fund and the Thames Rivers Trust for funding the Plastics Action project.

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SESSION III - RESTORATION: TRADE-OFFS AND LEGACIES OF THE PAST

Bright spots of peatland rewetting

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INTRODUCTION

Conservation and rewetting of the world's carbon densest ecosystems, i.e., peatlands, plays a key role to reach global climate and biodiversity goals and support human health and wellbeing. The challenge to conserve more than 460 million ha of (near)natural peatland and to rewet 50 million ha of drained and/or degraded peatland is huge and large-scale restoration of drained peatlands is just about to begin (Tanneberger et al. 2021).

While the concept of sustainability and restoration of natural resources has long been established in silviculture, peatlands have been treated with neglect although already the world's first scientific book on peatlands (de Schook 1965) included a chapter on peatland restoration and addressed the question of their long-term use. The overall approach towards peatlands, however, did not reflect this insight. Instead, peatland drainage was, for a long time, considered a cultural achievement allowing for land reclamation for agriculture and settlements (UNEP 2022).

Richard Lindsay (1992) introduced the term „Cinderella syndrome“ to describe how peatlands were neglected in nature conservation and public discourse because the parallels between Cinderella in the fairytale, whose beauty and importance are not recognised, and society's view of peatlands were quite striking. While rewetting and restoration of peatlands are now discussed much more widely (e.g., Zak & McInnes 2023, Temmink et al. 2024), the early warning from Findorf (1764) that restoration success may be slow can only now be quantified at a substantial amount of rewetted sites, across continental scales and multiple ecosystem functions. Kreyling et al (2021) show that rewetted peatlands are indeed often „novel ecosystems“.

Starting in the second half of the 20th century, first efforts to restore peatlands mainly focused on previously extracted areas, while now more and more also rewetting of agriculturally drained peatlands is addressed.

Recognizing the need to address the existing challenges in peatland conservation and rewetting, this work attempts to balance the problem-oriented focus of many peatland scientists and practitioners with a positive perspective that emphasizes the successes achieved despite the difficulties. By reviewing peatland conservation and restoration projects across various metrics, we identify 'bright spots', i.e. specific successful locations or projects that can serve as models for future restoration efforts. We want to start a participatory process to develop positive narratives whose aim shall not be to soothe our conscience but to guide us further by providing positive examples, lessons to learn and guidelines for future conservation, rewetting, and restoration efforts.

METHODS

Based on brainstorming sessions we tried to collect as many positive examples of successful peatland conservation/rewetting projects. It soon became obvious, that we need to address different categories of „projects“, because also regulatory changes like putting in place a new law, can be understood as a „bright spot“, when it affects peatlands positively. We differentiate the following categories of bright spots in peatland protection and restoration:

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- Putting large scale regulations into practice (like, e.g., including protecting peatland functioning within the Ramsar Convention or developing a first of its kind EU nature restoration law[1] or the large efforts Indonesia has undertaken
- Successful wide scale public funding for peatland restoration, like within the EU Life programme
- Successful privately financed restoration efforts, like those reported and organised under www.wetlandswork.org (Chesapeake Bay) or reflected in restoration success stories from the San Francisco Bay
- Science based provision of peatland rewetting and restoration methods like the Canadian moss layer transfer technique or similar approaches that have been tested in Germany
- Development of alternative, wet land use options that pave the way for sustainable income opportunities while protecting the peat, i.e. paludicultures or photovoltaics under permanently waterlogged conditions

A first compilation of projects along these lines is derived. The identified projects are assigned to the above categories and where possible, data on costs and monitoring results are included.

RESULTS and DISCUSSION

What we present is very much work in progress and we hope that we can convince our colleagues to contribute to this work. First results suggest that peatland restoration efforts can be successful over large spatial scales, persist for decades and yield benefits for climate, water supply, biodiversity, and land subsidence while still being cost effective. These bright spots highlight that restoration of peatland ecosystems can be used as a nature-based solution to mitigate climate, conserve and restore unique biodiversity and support human livelihoods. Despite being in its infancy, peatland conservation and restoration holds immense potential for rapid advancement and can unlock a range of services and innovative wet land use options that benefit nature and tackle grand societal challenges.

CONCLUSIONS

The task we have before us is enormous. In many peatland-rich regions, drainage-based land use is still a vital source of income, but it also contributes substantially to the multiple crisis humanity currently faces including climate change, biodiversity loss and water scarcity. Building resilient land use systems for the 21st century is unquestionably a difficult endeavour that requires positive energy and the best available knowledge and data. We propose to learn from light house projects, to foster a solution-oriented debate and to inspire policy makers, land managers, and communities to take action. True progress starts with a positive narrative about desirable futures and how we can achieve them.

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SESSION III - RESTORATION: TRADE-OFFS AND LEGACIES OF THE PAST

Rewetting without land-use change: Have your peat and eat it too

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INTRODUCTION

Agricultural drainage is a primary driver of peatland degradation, causing massive emissions and biodiversity loss, putting an enormous strain on the environment. Water level management (WLM) is a potential solution for peatland restoration, typically involving a land-use shift to paludiculture or nature. This conflicts with current stakeholders, who rely on current land-use, livestock farming, for their livelihood.

When measures are taken to improve one ecosystem service (i.e. emission reduction), other ecosystem services are bound to be affected. The vegetation community might shift towards wetland-tolerant or wetland-specific species (a win-win scenario), but stored phosphorus could be released under anoxic conditions (a trade-off).

This study explored the possibility of an intermediate step towards rewetting, where WLM is implemented without immediately changing the current land use. We investigated the effects on the target ecosystem service (emission reduction), as well as the biogeochemistry and vegetation diversity.

METHODS

We visited fourteen agricultural peatlands in Friesland (the Netherlands) and several extensive agricultural peatlands in Mecklenburg-Vorpommern (Germany). On seven Dutch sites, one of three water level management practices were implemented:

1) Sub-surface irrigation; stabilization of the water table using tubes at 50 cm below the surface

2) Furrow irrigation; furrows or ditches transport water near surface level along the pasture.

3) Dynamic ditch water level regulation: The pasture is drained whenever the farming practices (such as grazing and mowing) immediately require it. A higher water level is maintained otherwise.

In the results, these measures will be grouped as WLM because the direct effects on water levels did not differ significantly, while having the same intended effects. Grouping these three measures allows for more treatment replicates, increasing statistical power.

We conducted vegetation diversity monitoring on each of the sites during the summer of 2023, as well as soil sampling for biogeochemical analyses. On each of the Dutch sites, we measured emissions using novel chamber systems.

RESULTS and DISCUSSION

The implemented WLM measures resulted in a significant increase in water level, showing their intended direct effect (Figure 1B). Our results did not show the expected consequences of WLM on greenhouse gas emissions, though. Our measurements did fit the trend published by Tiemeyer et al. (2020) well, but did not show a significant relationship on an annual basis.

WLM also did not significantly affect vegetation diversity (Fig. 1A). Furthermore, the species richness per site, Shannon diversity, and species richness across all sites were much lower than expected, even relative to our expectations for cattle pastures.

We hypothesize that the WLM did not show a significant effect because its effect size, which allows for the persistence of the current land use, is negligible. The range in land use intensity, expressed as grass harvest and fertilization, strongly correlates with increased vegetation diversity, showing the need to reduce LU intensity. While emissions did not show the same relationship with land use, we can deduce from the literature that a significant reduction in greenhouse gas emissions requires a water table close to the surface level, around 10 cm below (Tiemeyer et al., 2020; Evans et al., 2021). This is incompatible with intensive agriculture as well.

WLM alone does not effectively mitigate emissions or benefit vegetation without a land-use change, but coupling WLM with a reduction in land-use intensity correlates with an increase in diversity, with effective emissions reduction also leading to land-use change.

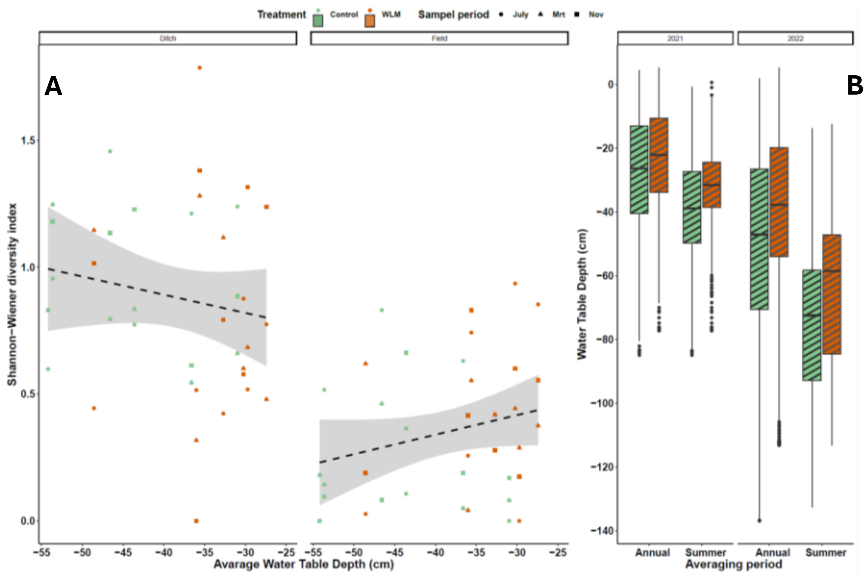

Fig.1. A) Shannon diversity as a factor of water table depth and B) water table depths during 2021 and 2022

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SESSION III - RESTORATION: TRADE-OFFS AND LEGACIES OF THE PAST

Effects of different irrigation techniques on *Sphagnum* growth and nutrient dynamics in *Sphagnum* paludiculture

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INTRODUCTION

Rewetting drained peatlands is crucial for restoring their ecosystem functions, e.g. carbon storage and unique biodiversity (Joosten et al. 2012, Gunther et al. 2020). Paludiculture, the cultivation of wetland plants on rewetted peatland, such as *Sphagnum* (peat moss), holds the potential to promote sustainable land use, biodiversity, and carbon and nutrient sequestration (Gaudig et al. 2018, Temmink et al. 2017, Vroom et al. 2020).

Sphagnum paludiculture sites require infrastructure for irrigation to keep the water table close to the moss surface (Gaudig et al. 2018, Pouliot et al. 2015). However, there are considerable methane emissions associated with the application of conventional ditch irrigation (Daun et al. 2020), which calls for improved water management techniques.

METHODS

Our study investigated the growth and nutrient dynamics of *Sphagnum* in a paludiculture setting in North West Germany for three years with four water management techniques: (1) control (ditch distance of 10 m), (2) reduced amount of irrigation ditches (distance 35 m), (3) gravity irrigation with subsurface pipes, and (4) pressurized irrigation with subsurface pipes. After 1,5 years, due to clogging of the subsurface pipes, treatments 3 and 4 received ditch overflow irrigation for the remainder of the experiment.

RESULTS and DISCUSSION

Our experiment showed that none of the new techniques functioned as well as the control. In addition, our findings suggest that after three years both of the subsurface irrigation treatments produced a similar amount of *Sphagnum* biomass as the control (Fig.1). Moreover, next to substantially lower biomass, we found indications of drought stress, P and K limitation within the reduced amount of irrigation ditches treatment.

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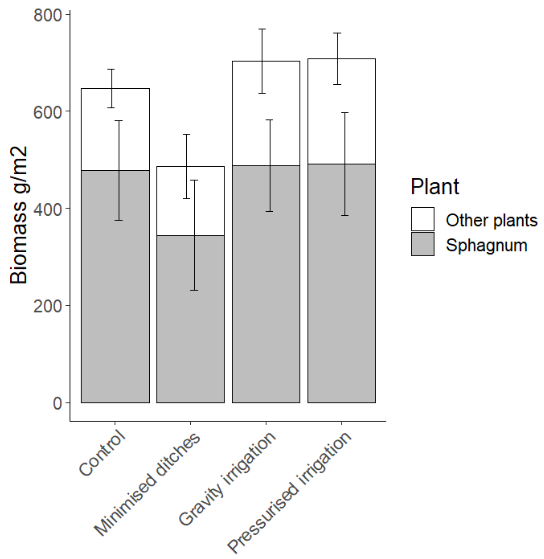

Fig. 1. Biomass (g/m^2) of *Sphagnum* (grey) and other plants (white) in November 2023 in four treatments three years after establishment.

CONCLUSIONS

We conclude that a 35 m ditch distance is too much to support optimal *Sphagnum* growth, and subsurface irrigation does not improve *Sphagnum* growth and nutrient dynamics compared to the control. Further research is needed to explore alternative emission-reducing irrigation techniques for *Sphagnum* paludiculture.

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SESSION III - RESTORATION: TRADE-OFFS AND LEGACIES OF THE PAST

Learning to think like the landscape. How to avoid trade-offs and maximise synergies in wetland restoration

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INTRODUCTION

The above anthropomorphic approach to nature is, of course, a metaphor, but in my intention it is nevertheless more than a rhetorical figure. My initial premise is that the landscape is much more than the sum of perceptible attributes of space. This visual layer is a mere demonstration of the processes taking place in the physical and biological dimensions and the interactions between them, particularly acting as negative and positive feedback loops. Moreover, the natural landscape is a functional system in which individual elements - ecosystems - have functions and places assigned through biological and system evolution. Water is the most important connector of this system. In the lowland landscape of Central Europe, the distribution of individual ecosystems in the catchment both depends on and shapes the flow of water through the landscape - controlling water resources in terms of quantity and quality. Forests, peatlands, streams, riverside wetlands, floodplains, and oxbow lakes are pieces of the ecohydrological puzzle that make up a functional landscape, characterized by resilience, i.e. the ability to respond to change while maintaining key functions. Whereas large-scale catchment transformations have fundamentally disrupted this landscape resilience, depriving individual (wetland) ecosystems of their functions, ecological restoration should aim to reconstruct it. Based on examples of peatland landscapes from lowland Poland I will argue that our approach to restore functionality of degraded landscapes should stem from ecohydrological landscape analysis and aim to reconstruct zonation patterns and the lost interdependence of different wetland ecosystems rather than re-create original ecosystems in their pre-degradation locations.

METHODS

This paper is based on a review of source literature, including my own research on fen vegetation ecology and a series of case studies from lowland Poland – wetland landscapes which I analyzed for various purposes together with colleagues from our research group and Wetland Conservation Centre.

I will refer to the following features of wetland types in functional landscapes and assess their restorability in degraded systems: primary productivity, water retention and microclimatic control, carbon balance and global warming potential, nutrient removal and water cleanup, biomass utilization options and, last but not least, species richness, species rarity and conservation importance.

The following analyses helped to gain overview of wetland development and their functioning in the landscape: botanical and phytosociological inventories or reconnaissances, productivity measurements of shoots, roots and bryophytes, groundwater depth measurements in piezometers, in-situ peat stratigraphy analyses, digital land elevation models, and drainage system inventories. Additionally, socio-economical and land ownership situation was assessed, using open data sources, as well as direct interviews with stakeholders.

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RESULTS and DISCUSSION

Lowland wetland landscapes have been developing in Central Europe at least since the onset of Holocene 11.5 thousand years ago. However, the feedback mechanisms – between individual plant level (shaped by genetic evolution) and the landscape / riverscape level (shaped by system evolution in the informatics sense) are much older, having developed over hundreds of millions of years. The position of different types of wetlands in the landscape is an effect not only of the original water flow and water quality, but also reflects different stages of successional development of these ecosystems, as well as whole landscape development. Wetlands accommodate available water and chemical energy (nutrients) responding to both external forces (climate, base geomorphology) and internal feedbacks (autogenic processes). As a result of water-resistent properties of peat, mires expand upward the slopes, as well as lead to rise of water tables in surrounding landscapes, thereby initiating development of new mires, that would eventually merge as mire massives. This process has been disturbed almost everywhere in Central and Western Europe, braking up landscape functionality. In most cases, which I review, protected remnants of degraded mire ecosystems suffer from drainage located in other parts of the former system, usually the lowest-lying parts and often originally the oldest ones.

I will argue that only a complex approach, in which the whole landscape is taken into account, allows for the achievement of both climate goals (minimizing peatland emissions), biodiversity goals (restoration of disturbed stands of protected mire species) and minimizing social conflicts. Ecohydrological landscape analysis combined with a socio-economic outlook allows for sound zonation of landscape functions. However, the key to (partly) restoring them, lies in the lowest-lying, intensively drained, sites. We sometimes have to accept completely novel ecosystems with new functions as targets in these parts of wetland landscapes, in order to prevent their further deterioration and re-create groundwater pressure in the surrounding landscapes. In my examples I will deal with: wild swamp, paludiculture cropland, shallow pond system or a wetland recreational park.

ACKNOWLEDGEMENTS

Several of the localities reviewed were analyzed within the project “Remember about wetlands” by Wetlands Conservation Centre (Centrum Ochrony Mokradeł), I want to thank Magdalena Siemaszko and Olga Roszkowska, co-ordinators of this project. Other sites were assessed with students of my course “Mire ecosystem conservation”, and my thanks go to the students as well as my colleagues, who jointly led the course, especially Łukasz Kozub and Iza Jaszczuk.

SESSION III - RESTORATION: TRADE-OFFS AND LEGACIES OF THE PAST

Time for a change in peatland forest management: rewetting delivers €100 billion more than wood production

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INTRODUCTION

Traditional forest management systems aim at maximizing timber production, in comparison new policy calls for sustainable forest management and multiple benefits of entire forest landscapes. This calls for learning through evaluation to support the implementation of policies aiming towards multi-functional forest landscapes. The aim of this study is to quantify the economic trade-offs among natural, current, and re-wetted peatland forests using seven indicators, viz. drainage maintenance, rewetting, water retention, wood production, and three types of carbon sequestration as economic indicators.

METHODS

A 3-step framework was applied to assess the trade-offs between Lithuania's peatland forest (302 000 ha) and the benefits delivered by wood production, water retention and carbon sequestration for three different peatland forest conditions (potential natural, current, and rewetted (Fig 1).

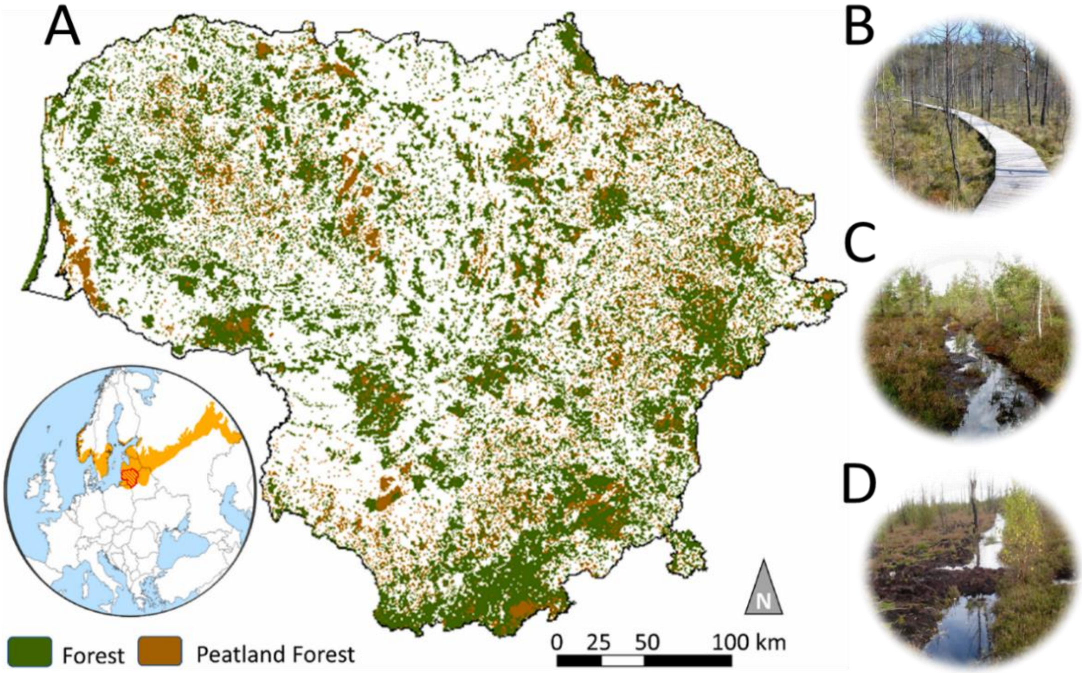

Fig. 1. Distribution of Lithuanian's peatland forests (A) and the three peatland conditions: Natural (B), Current (C) and Rewetted (D).

SESSION III - RESTORATION: TRADE-OFFS AND LEGACIES OF THE PAST

RESULTS and DISCUSSION

The cost benefit analysis showed that in a potential natural state, Lithuania's peatland forests would deliver an economic benefit of~€176.1 million annually. In contrast, compared to natural peatland forests, the drainage of peatland forests for wood production has caused a loss of ~€309 million annually. In comparison, peatland forest rewetting is estimated to increase the economic value by ~€170 million annually (Fig 2). This study shows that satisfying different ecosystem services is a balancing act, and that a focus on wood production has resulted in net losses when foregone values of water storage and carbon sequestration are considered. The value of different sets of ecosystems service benefits and disservices must be assessed, and can be used as a tool towards creating, implementing, and monitoring consequences of policies on both sustainability and biodiversity. Actions are needed to adapt to and mitigate the effect of forest draining on climate change toward securing multi-functional forest landscapes.

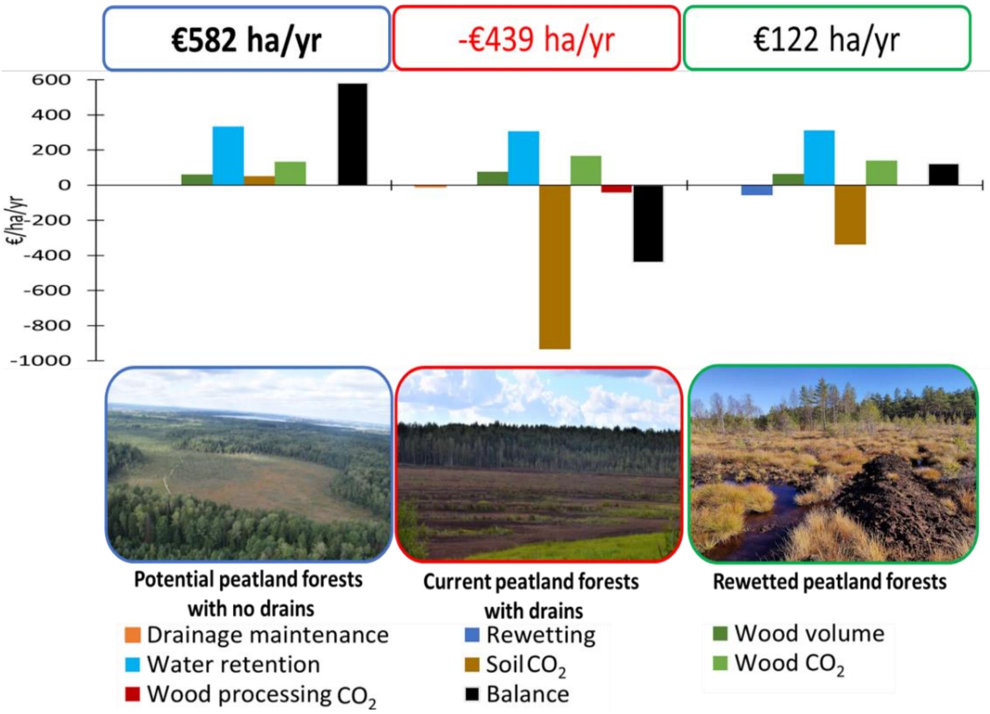

Fig. 2. A comparison of the estimated values of the seven indicators used for the 3 different peatland forest condition scenarios.

CONCLUSIONS

Managing a diversity of ecosystem services is a balancing act and supporting policy about multi-functional forest landscapes requires the assessment and valuation of different sets of ecosystem service benefits and disservices. In this case study, we found that the traditional focus of wood only forest management overlooks a whole suite of important ecosystems services that can help mitigate the negative effects of climate change for a broad range of stakeholders and societies. Using seven economic indicators *viz*. drainage maintenance, rewetting, water retention, wood production, and three types of carbon sequestration, we estimated that the draining of peatland forests have lost ~€307 million annually. Rewetting of drained peatland forests could transform these current losses into a benefit of ~€37 million.

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ACKNOWLEDGEMENTS

This research was carried in the framework of the European Union's Horizon Europe programme WET HORIZONS, grant agreement no. 101056848. Data acquired from the project DESIRE (Development of sustainable (adaptive) peatland management by restoration, Index number R3071, project number #R091 implemented in the framework of the Interreg Baltic Sea Region Program.

For more information see: Makrickas, E., Manton, M., Angelstam, P., Grygoruk, M., 2023. Trading wood for water and carbon in peatland forests? Rewetting is worth more than wood production. Journal of Environmental Management, 341, 117952, doi.org/10.1016/j.jenvman.2023.117952

SESSION III - RESTORATION: TRADE-OFFS AND LEGACIES OF THE PAST

Better Slow than Fast: another Rewetting Strategy

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INTRODUCTION

In the realm of climate change mitigation and adaption, it is imperative that peatland restoration strategies employed in Europe are meticulously designed to minimize any potential for exacerbating climate warming or contributing to net radiative forcing, both in the short and long term (Zak and McInnes et al., 2022). Furthermore, it is crucial to recognize and address other adverse consequences, such as downstream waterbody eutrophication, threats to biodiversity and socio-economic impacts, in order to optimize the overall gains from restoration endeavors. Currently, there is a lack of knowledge regarding the most effective practices for peatland restoration that can maximize societal benefits.

METHODS

Three different strategies, namely the frequently practised ‘peatland inundation’ in comparison to the less commonly utilised but promising strategies of ‘topsoil removal’ and ‘slow rewetting’, have been selected for consideration within this discourse (Fig. 1). Given that the former strategy may give rise to certain adverse consequences, it raises the fundamental question of whether alternative restoration methods should be more widely adopted across Europe.

RESULTS and DISCUSSION

The impacts of restoration strategies vary, particularly concerning their effects on greenhouse gas emissions and waterborne nutrient fluxes. Thus, the common rewetting of peatlands has often led to the formation of shallow lakes, usually characterized by large methane emissions, high mobilization of nutrients, and slow development of target vegetation over decades (Kreyling et al., 2021). The removal of upper degraded peat soils, often less than 30 cm thick, before rewetting can mitigate high methane emissions, minimise nutrient availability and benefit both an active reintroduction or passive recolonisation by oligotrophic plants (Zak et al., 2018). According to our recent understanding of the processes and factors controlling nutrient mobilization and greenhouse gas emissions, a more controlled and progressive ‘slow rewetting’ strategy is proposed as an alternative to spontaneous inundation of long-term drained peatlands or costly topsoil removal. However, there are larger uncertainties for the timeframe under consideration and, in general, there is an absence of data in particular for the slow rewetting strategy.

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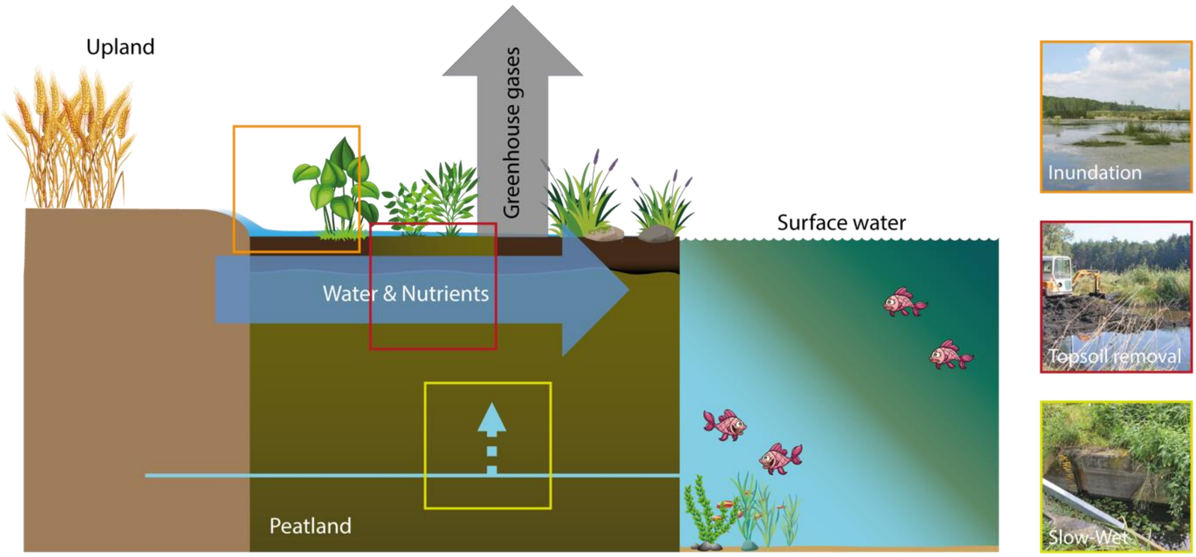

Fig. 1. Three rewetting strategies 1) "inundation", 2) "top soil removal", and 3)"slow rewetting".

CONCLUSIONS

Policy-makers and practitioners must grasp how peatland restoration can contribute significantly to global efforts which target climate change and the biodiversity crisis. Peatland scientists should communicate their insights effectively in a language understood in broader policy discussions and practical applications. Ultimately, restoring peatlands and the path chosen for restoration are societal decisions. It's vital that society comprehends the potential pros and cons of restoration to make informed choices.

ACKNOWLEDGEMENTS

This work is a contribution to the NIFA project 'Effekter ved fjernelse af topjord på fosfortab, drivhusgas emission og biodiversitet i vådlagte organiske lavbundsjorde' (33010-NIFA-20-754).

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SESSION III - RESTORATION: TRADE-OFFS AND LEGACIES OF THE PAST

Raising the water level by simple ditch blocking did not improve nutrient retention in a fen

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INTRODUCTION

Organic soils have been intensively drained for the purpose of e.g. agriculture and forestry since around the 1960's with the implications of large emissions of carbon dioxide, decreased biodiversity, and deterioration of water quality. Due to the many adverse effects of drainage, there has been an increasing focus on restoring these areas during the past three to four decades, often with a narrow focus for each individual project aiming to improve either, carbon balances, biodiversity, or mitigation of nutrients.

METHODS

On April 26th, 2022, the 239-ha fen of Lobæk in Southern Jutland, Denmark was rewetted with the aim to reduce emissions of carbon dioxide. The rewetting was accomplished by strategically blocking the ditches at different locations with dams to raise the water level across the entire area.

For one year prior to rewetting and two years after rewetting, we monitored daily discharge and nutrient fluxes (total nitrogen, nitrate, ammonium, total phosphorus, and soluble reactive phosphorus) at four streams discharging into the fen (Fig. 1), in the middle of the fen area where the four streams merge/meet, and at a the outlet of the fen using continuous measurements of water stage and Doppler velocity and automated water samplers in combination with triweekly grab samples and point measurements of stream discharge.

RESULTS and DISCUSSION

Analysis of nutrient concentrations and fluxes revealed only minor or no significant differences before and after the rewetting process at the middle station and at the outlet. Since we only had one year of measurements before rewetting, one could argue differences in climate could obscure potential differences in nutrient fluxes. However, no significant differences could be detected in concentrations and fluxes at the four stream stations feeding into the fen area before and after rewetting.

The approach of simply blocking the ditch at discrete locations may effectively raise the water level and thereby reduce emissions of carbon dioxide. However, this approach is likely too simple to also have a positive effect on nutrient retention. The simple blocking of the ditch at discrete locations still leaves long stretches of the ditch passable for swift passage of water, decreasing residence time and interaction between the nutrient-rich water and the organic fen soils.

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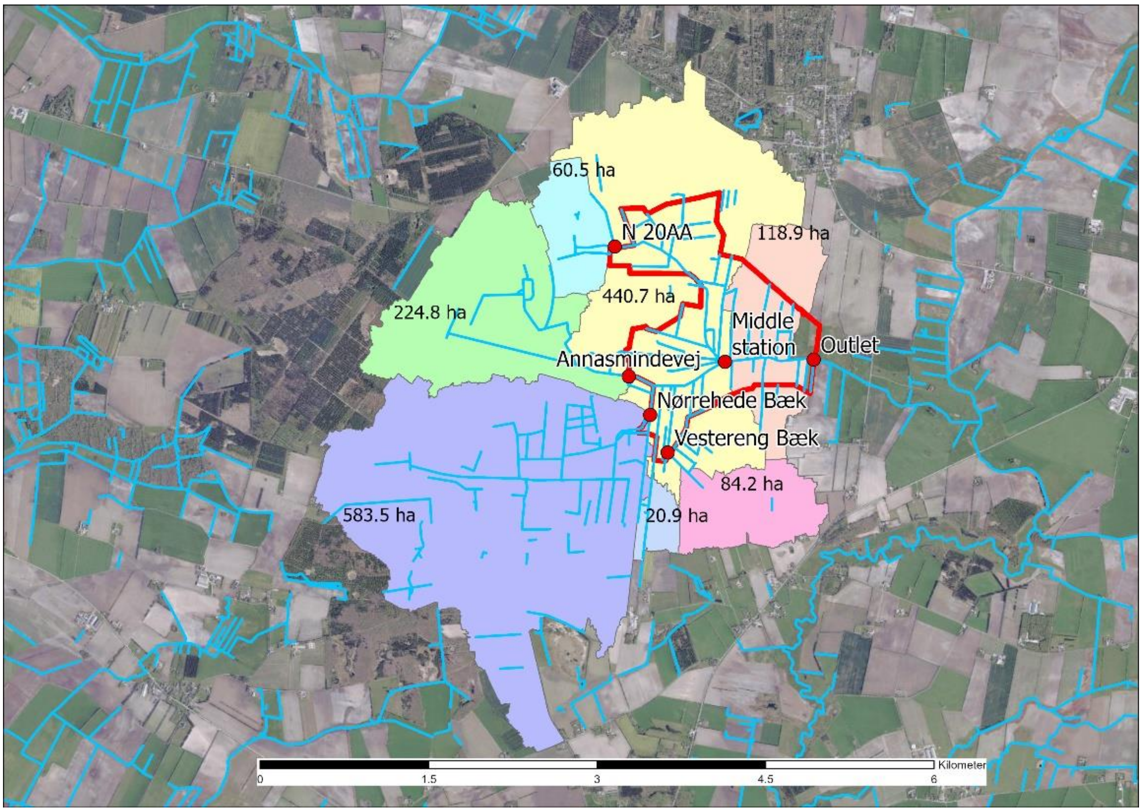

Fig. 1. Map of the fen including surrounding stream catchments and area.
Red dots show monitoring stations (water level, Doppler measurements, and water sampling).
Middle Station, where four inlet streams merge. Søbæk is outlet from fen site.

Table 1. Mean concentrations of unfiltered samples of TN and TP at the four inlet streams, Søbæk Middle station and at the outlet Søbæk stream, before and after rewetting. With 95 % confidence limits.

Stream	TN before	TN after	TP before	TP after
Annasmindevej	5.941 ± 0.967	5.599 ± 0.485	0.080 ± 0.032	0.084± 0.038
N 20AA	1.924 ± 0.679	1.612 ± 0.386	0.080 ± 0.053	0.059 ± 0.019
Nørrehede Bæk	2.564 ± 0.483	2.396 ± 0.268	0.054 ± 0.024	0.063 ± 0.034
Vestereng Bæk	2.847 ± 1.217	2.084 ± 0.658	0.147 ± 0.251	0.104 ± 0.069
Søbæk Middle	3.551 ± 0.859	3.139 ± 0.348	0.084 ± 0.025	0.137 ± 0.047
Søbæk (out)	3.237 ± 0.560	2.864 ± 0.345	0.080 ± 0.017	0.112 ± 0.045

CONCLUSIONS

Our findings suggest that solely targeting the reduction of carbon dioxide emissions through the rewetting of organic soils may not guarantee improvements in other critical ecosystem services, such as nutrient retention. To maximize the benefits of rewetting efforts, a more comprehensive approach is necessary, prioritizing the restoration of natural hydrological processes.

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Paludiculture – future wetland generation from degraded peatlands

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INTRODUCTION

Paludiculture is a land use strategy in wetscapes (wet peatland landscapes), which combines the productive use of wet peatlands and the provision of ecosystem services. Wetland ecosystem services provide, among others, water retention, biomass production, and intact soil carbon stores. Regulating services may also facilitate water purification, flood control, wildfire prevention and regional cooling.

Important drivers of ecosystem service provision are water level and vegetation dynamics. Typical wetland species can be farmed as paludiculture plants and crops, such as *Sphagnum*, *Carex*, *Phragmites*, *Typha* and *Alnus*. Some species of these genera have been recognized as important peat forming plants that can conserve soil carbon. While knowledge regarding biomass yields is quite well established, little is known about species-specific potential to promote ecosystem services in wet and rewetted peatlands.

Here, we summarize findings from a range of paludiculture field studies and mesocosm experiments. The data are discussed and compared to existing paludiculture literature and a farm scale model of ecosystem service provisioning.

METHODS

In the different paludiculture fields and trials we recorded data on water level dynamics, biomass productivity, soil carbon (C) sequestration potential, and greenhouse gas emissions as measures for ecosystem services. Water level dynamics were measured by automated water gauges and hand measurements. We calculated water storage based on soil cores from the upper 40 cm and inferred water retention potential from flooding experiments and field water level observations. For C sequestration potential we collected volume-sensitive cores (10 cm by 10 cm) and determined carbon density.

The emissions of carbon dioxide (CO_2) and methane (CH_4) were determined either by eddy covariance or by cooled static chamber measurements. Nitrous oxide (N_2O) emissions were also measured using chambers. We extrapolated CO_2 and CH_4 fluxes to yearly budgets of net ecosystem exchange using Random Forest machine learning or fitting of environmental parameters, assuming a non-linear relationship. For a subset of sites, we quantified C input by extrapolating concentrations of dissolved organic/inorganic C and pumping volumes over time. We measured potential C export by harvesting and drying biomass in both late summer and winter months.

SESSION III - RESTORATION: TRADE-OFFS AND LEGACIES OF THE PAST

RESULTS and DISCUSSION

Paludiculture practices in Germany and the Netherlands can effectively raise water levels close to the soil surface at a water table depth (WTD) that conserves soil organic matter and peat. Sphagnum paludiculture had a water management system in place that aimed at maintaining WTD -5 cm to -10 cm from the surface. Pilot farms with Typha and Phragmites aimed to establish flooding of +10 cm to + 20 cm above the surface. Maintaining high water levels required additional water input. Ongoing drainage in the direct vicinity of the Typha and Phragmites pilot plots may have been the main cause of high water demand and the need for irrigation.

Farming Phragmites, Typha and Sphagnum greatly increased the peat soils' water storage and ability to retain water over longer periods (Fig. 1). Flood control may exceed 12 000 m^3 ha^{-1} $event^{-1}$. We found that in Sphagnum cultures, water storage capacity was related to water quality (alkalinity). Flooding of Sphagnum should be limited to 2 to 5 days during the growing season or avoided entirely by promoting sponge formation.

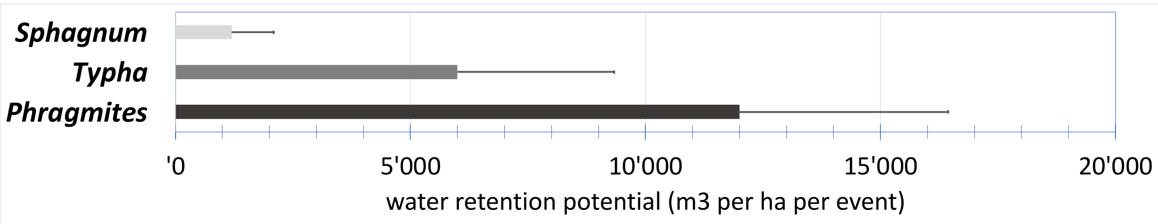

Fig. 1. Paludiculture water retention potential of 3 typical flood tolerant crops (mean and standard error).

Growing flood-tolerant paludiculture crops in combination with water levels close to the surface increased the C sequestration potential of the soil. Well-managed Sphagnum paludiculture showed the highest C sequestration potential (up to 3.3 t C ha^{-1} yr^{-1}). This potential may come, however, at the expense of long-term harvest yields as the sequestered C mainly consists of Sphagnum biomass and moss litter. In contrast, growing Phragmites combines above-ground biomass harvest with below-ground C sequestration. For Phragmites, C sequestration potential was up to 2.6 t C ha^{-1} yr^{-1}. The stability of the newly buried C warrants further investigation across water tables and productivity gradients.

Paludiculture pilot sites and farms reduced the emission of greenhouse gases (GHG) compared to their drained counterparts. The climate mitigation potential (20 to 26 t CO_2eq. ha^{-1} yr^{-1}) was highest in Sphagnum paludiculture when harvest, ditches and a limited area of drained infrastructure were also accounted for (German sites). Phragmites cultures approached a GHG balance close to zero before harvesting and exporting biomass C. The production and release of CH_4 in Typha and Phragmites in Dutch paludicultures equalled or exceeded CH_4 emission rates of dairy livestock on a per hectare base. Carex sites revealed lower CH_4 emission rates than dairy livestock CH_4 emission.

We discuss factors, which control CH_4 production (easily degradable C from the inlet (pumping) water, algae production in open waters, and rhizospheric C release) and options to mitigate wet CH_4 emission. Emission of N_2O was very low (<1 t CO_2eq. ha^{-1} yr^{-1}) compared to drained peatlands and net uptake was regularly observed. For Typha, Alnus and Phragmites, the GHG balance was greatly reduced when water-borne C-import and long-term carbon storage in paludiculture biomass products were taken into consideration, suggesting a net cooling effect.

CONCLUSIONS

Paludiculture practices succeeded in creating and regenerating wetlands. Growing and using paludiculture plants and crops improved and stabilized ecosystem service provision. In the future, management practices may further develop to mitigate trade-offs, support plant health, and decrease the dependence on active water management. Future paludiculture research should include biodiversity dynamics and policy instruments to create regional business opportunities. Finally, paludiculture ecosystems may become vital wetland buffers in space and time to form healthy wetscapes.

ACKNOWLEDGEMENTS

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Quantification the Mowing and Draining Debate using a model of the Biebrza Wetlands

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INTRODUCTION

Human activities, such as moving or draining peatlands can have significant impacts on the peatland environment. Peatlands have primarily undergone extensive drainage for agriculture, forestry, and peat extraction (Fluet-Chouinard et al., 2023). Draining peatlands can lead to significant environmental impacts, such as growth of groundwater contamination, shifts in biogeochemical equilibriums, and increase in chloride concentrations due to changes in water table dynamics and vegetation influence (Renaud et al., 2023). Bring et al. (2022) concluded numerous studies to examine the effects of restoring, constructing, or draining wetlands on groundwater levels.

From the point of view of the peatlands' "service" for the operation of the entire Earth's ecosystem, we will focus on a selected aspect of counteracting climate change and its predicted effects: i.e. groundwater retention. With the Biebrza River and the adjusting peatland in Poland (Europe) as a case study, we will show if/how human activity can contribute to changes in groundwater table in peatland and, in consequence, water retention.

METHODS

Study area

The Upper Biebrza Valley, is located in North-East Poland (Fig 1a). In this area, the Biebrza River remains unregulated. In 1992, the Biebrza National Park was established, which includes the case study area, where the protection measures include a prohibition on activities such as river mowing and removal of water vegetation. Given that the hydrological character of the Biebrza Wetlands remained undisturbed, many scientists treat it as a suitable research area to study the natural peatland environment.

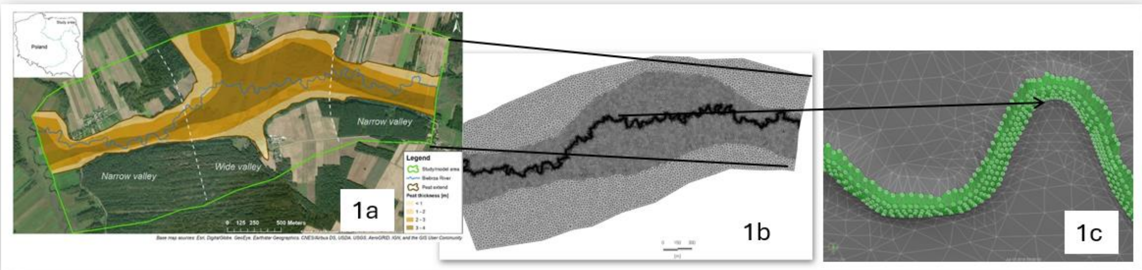

Fig. 1. Upper Biebrza Valley – study area and its' model representation
(based on Grodzka-Łukaszewska et al., 2022)

SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

Modelling approach

The Upper Biebrza groundwater flow model was used to calculate scenarios of different human activities and its environmental impact into the surrounding peatland (Grodzka-Łukaszewska et al, 2022). The model (Fig 1b) was calculated using FEFLOW and focused on detailed mapping condition in the riverbed and its hyporheic zone. The river itself was defined in the model using 1st type of the boundary condition, riverbed conductance was mapped by defining the hydraulic conductivity properties. The detailed representation of the riverbed shape can be found in Fig. 1c. The detailed model constitute the base for various scenarios of maintenance activities that are conducted in peatland were calculated.

The modelling activities focused on calculation of scenarios of mowing of the riverbed, K1 ... K6, which represent different intensities of mowing the riverbed in the same hydrological situation. Additionally, current reference state of the modelled section of the river (R) was considered. The Fig. 2 presents two extreme (R, K6) and an average scenario (K3) of riverbed mowing.

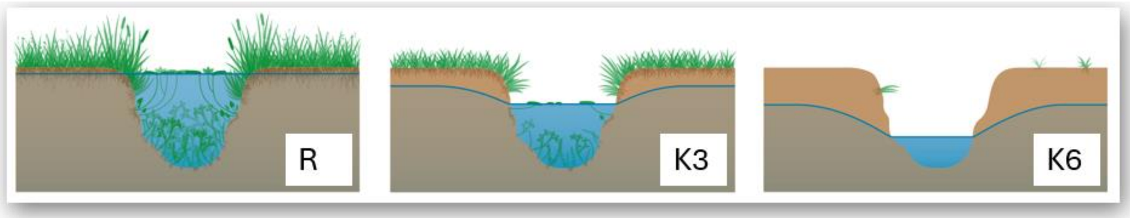

Fig. 2. Schematic visualization for three scenarios for mowing the riverbed (R- current state; K3- average mowing; K6- complete mowing)

RESULTS and DISCUSSION

The water balances were compared for each scenario of mowing (Figure 3). The analysis focused on water exchange between peatland and river. The results of comparing these balances for K6 scenario clearly indicate an increase in water outflow from peatland to the river from 16 to 26%, depending on the width of the valley. This may mean that, if the river bed is completely mowed, we can expect that the outflow of water from the peatland into the river will increase by up to 25% (compared to the reference state).

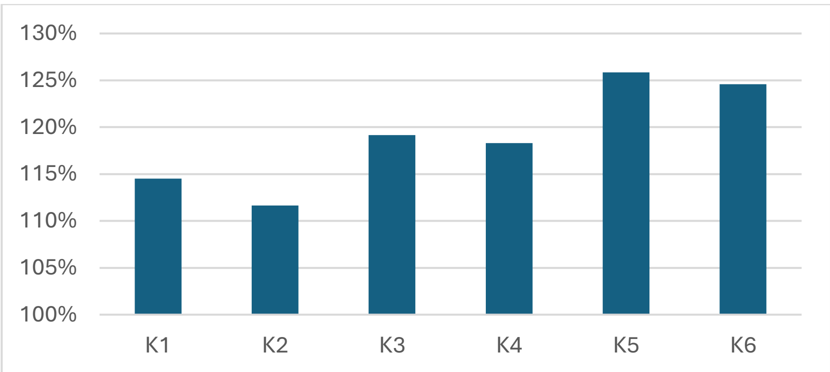

Fig. 3. Increase (%) of water outflow into the river from the Upper Biebrza Wetland for different scenarios of mowing the riverbed.

SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

The services provided by peatlands are optimal only when water levels are at the appropriate level. Unfortunately, wetlands once drained lose their extremely valuable environmental properties, and rewetted wetlands do not fully return to their original functions (Ralphet al, 2023; Kreyling et al., 2021 or Schwieger et al., 2021).

The presented research concerns one example of a peatland not significantly changed by human activity, so, we conclude that it is a good example illustrating the potential impact of mowing the riverbed on changing the water balance in the peatland. We are aware, however, that changing the peatland's water balance depends on many environmental and human factors and we believe that this work may also contribute to a wider context of discussions on peatland conservation.

ACKNOWLEDGEMENTS

The results of the activities presented in the abstract were performed as part of the project HORIZON (101112738); SpongeScapes; "Evidence and Solutions for improving SPONGE Functioning at LandSCAPE Scale in European Catchments for increased Resilience of Communities against Hydrometeorological Extreme Events"

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SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

Spatially explicit hydrological flow processes and river-floodplain coupling in the Biebrza Lower Basin

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INTRODUCTION

River floodplain wetlands are highly diverse and productive ecosystems. However, their ecosystem services are under threat by global change processes. The associated threats for society are expected to increase in the future, but adequate management of ecosystem services could limit degradation of environmental processes and their associated ecosystem. Hydrological dynamics over space and time – changing from day to say, season to season and between years - are the major factor that steers abiotic and biotic floodplain processes (Tockner & Stanford 2002), that determine nutrient availability, productivity and biodiversity. The Flood Pulse Concept (Junk et al., 1989) describes the coupling of yearly river dynamics and adjacent floodplain processes, defining the moving littoral as the indicator of the zone of high productivity. Where multiple hydrological flow processes play a role in flooding, this coupling is probably less straightforward then postulated by the concept. In that case there are unknowns related to: (1) the lateral reach of river flood water, sediment and nutrients on the floodplain; (2) the relevance of other water types besides river water for inundation water; and (3) the origin of deposited sediment and organic matter.

We studied temporal interannual and seasonal dynamics in water and sediment flows in the Biebrza Lower Basin to shed light on how temporally varying hydrological flow processes affect spatial floodplain water quality and sediment-attached nutrient and organic matter deposition, and how the resulting abiotic patters relate to biodiversity and ecosystem services.

METHODS

We collected spatial data on the hydrochemistry of the Biebrza Lower Basin floodplain inundation water over the period 2001-2012, and used PCA and *K*-means clustering to reveal coherent water quality types. These inundation water types were then linked to one of the principal water sources in the Lower Basin (Keizer et al., 2014).

In a follow-up study, along 3 transects from the river to the floodplain edge, we collected data on dissolved and sediment-attached nutrients, aboveground biomass and biodiversity, and topographical parameters. Lateral trends in aboveground biomass and species richness were compared to the spatial positions of i) the zone with high sediment-attached nutrient deposition, ii) the zone with river water flooding, and iii) the edge of inundation (Keizer et al., 2018).

A third study aimed to determine origins of deposited sediment-attached nutrients and organic matter, by collecting soil material from potential upstream (external) sediment sources (arable and non-arable) and from floodplain (internal) deposited sediment material. The soil material was analyzed on the parameters TOC and N, and on C and N isotopes. We added two additional potential sources based on literature: organic matter from undrained fen soil (Groß-Schmölders et al 2022) and algae (Finlay & Kendall 2007). The contribution distributions of all modelled sources were then calculated. To study the lateral trends, we performed regression analysis for the contribution of each sampled and potential source to the deposition sampling points.

RESULTS and DISCUSSION

Linking floodplain inundation water quality to principal water sources indicated that the lateral extent of river-derived floodwater is limited to a relatively narrow zone along the river (Fig. 1).

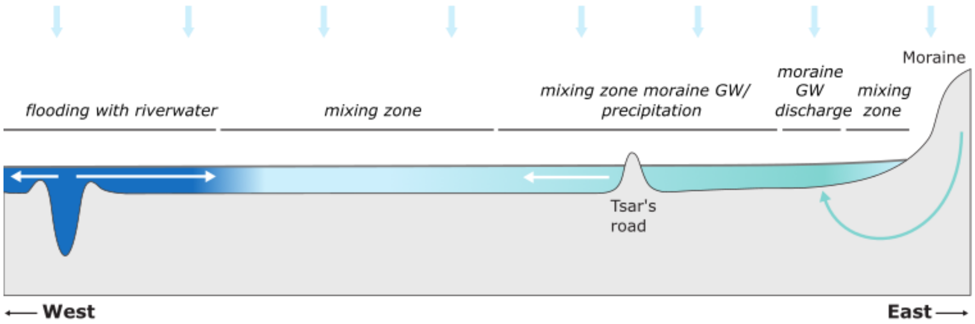

Fig. 1. Hydrological flow processes and interactions of principal water sources along a transect in the Biebrza Lower Basin, explaining spring flood inundation water type zonation (Keizer et al., 2014).

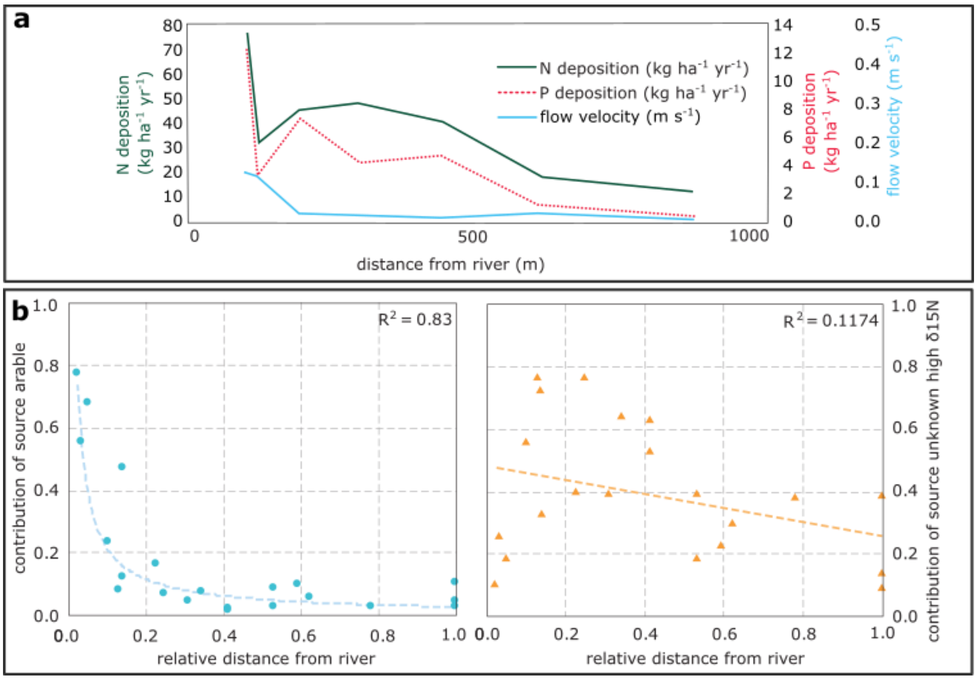

Fig. 2. a) Deposition of particulate sediment-bound N and P, and flow velocity along a transect in the Biebrza Lower Basin (Keizer et al., 2018) and b) lateral trends in contribution of the upstream arable source and unknown local source (high d15N, probably algae (Finlay & Kendall 2007)) to deposited sediment further support the lateral diminishing influence of the river.

Second, the particulate sediment-bound N and P deposition sharply decreased with distance from the river, indicating the rather limited lateral influence of the river for sediment input to the floodplain (Fig 2a).

As shown in Figure 2b, sediment-bound nutrient deposition of upstream arable land use was only high near the river and sharply decreased with distance. Nutrient release was also shown to be highest in this zone (Wassen et al., 2003). Flooding with dissolved nutrients seemed to result in high algae growth and deposition. In the zone with non-river derived inundation water, local erosion and deposition of soil organic matter from dead plant litter was probably the major process for sediment deposition. The three studies combined show how the hydrological flow processes of different water sources steer inundation water quality and sediment deposition distributions.

CONCLUSIONS

The main conclusion related to the relevance of the Flood Pulse Concept is that the moving littoral is not a good indicator of the zone of high productivity. Therefore, for temperate floodplains with multiple hydrological flow processes, we proposed three additions: 1) delineation of the edge of river floodwater; 2) delineation of the zone of particulate sediment-bound nutrient deposition; and 3) separating the zone where upstream nutrients are imported as either sediment-bound or dissolved and the zone where local recycling of soil material is the major term in the nutrient balance.

The ecosystem services sedimentation and nutrient retention are predominantly limited to a narrow zone along the river. For the service of biodiversity, the studies showed the importance of exfiltrating groundwater in the central part of the Biebrza Lower Basin.

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SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

Updating an Upper Biebrza Valley model based on unique real-time measurement of groundwater fluxes

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INTRODUCTION

Interactions between groundwater and surface water are of crucial importance for the ecological functioning of wetland systems since they control groundwater levels in the wetlands, water temperature in the river and exchange of solutes. Therefore, management practices aiming to conserve the ecological status strongly depend on estimates of groundwater – surface water exchange. However, currently established methods to estimate groundwater flow (i) rely on temporal point measurements, missing the effect of crucial short term events (e.g. precipitation), (ii) rely on differences in physical characteristics between the groundwater and surface water (e.g. temperature and/or conductivity), which are not always present or (iii) require extensive modelling.

STUDY AREA

The Upper Biebrza Valley, situated in northeastern Poland, features an unregulated Biebrza River, unreclaimed marshlands, fens, and grasslands, and a lack of extensive human intervention in the hydrological system. Designated as a National Park since 1992, protective measures include a prohibition on river dredging and on the removal of water vegetation. The Biebrza Wetlands, thanks to their mostly intact hydrological processes, have been the focus of extensive hydroecological research done by many researchers. The hydrological system of the Upper Biebrza Valley is comprehensively described in Grodzka-Łukaszewska et al. (2022).

METHODOLOGY

We performed the recalibration of a 3D transient groundwater model (Grodzka-Łukaszewska et. Al, 2022) based on time series of not only groundwater heads, but also in situ measured groundwater fluxes. This is absolutely unique and it involves the newly developed iFLUX sensors (Verreydt et al., 2021). Two versions of this sensors exist, for measuring horizontal and vertical flow, respectively. The sensor probe for horizontal flow consists of two bidirectional flow sensors that are superimposed and is installed in a monitoring well with dedicated pre-pack filter, allowing for measurement of both groundwater flux magnitude and direction. The probe measuring vertical flow can be installed directly in the soil, in the riverbed or in a monitoring well. With a broad measuring range of groundwater fluxes from 0.5 cm/day to 2000 cm/day and frequent measurements, this setup can map rapidly changing flow conditions.

SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

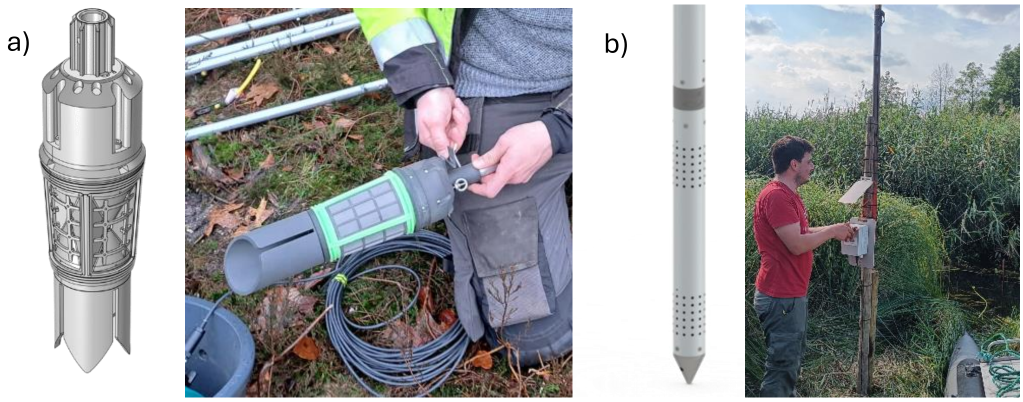

Fig. 1. Horizontal (a) and Vertical (b) iFLUX sensor probes, installed at in Stary Rogozyn.

We installed the iFLUX sensors in the upper Biebrza basin to (i) study the variability of groundwater fluxes and groundwater – surface water exchange on a small temporal scale and (ii) assess the possibility of incorporating groundwater flux data to reduce model uncertainty of a manually calibrated groundwater model.

RESULTS AND DISCUSSION

Our results show that, during most of the year, the Biebrza river is gaining, with a sharp increase in upward groundwater flux in the hyporheic zone during summer months. In the valley surrounding the river, groundwater flows towards the river, as expected. However, the data show a remarkable diurnal pattern of both flow magnitude and direction, with the highest flow velocity occurring in the late afternoon, suggesting a relation with evapotranspiration. After large precipitation events, the flow direction reverses, suggesting infiltration of surface water into the aquifer.

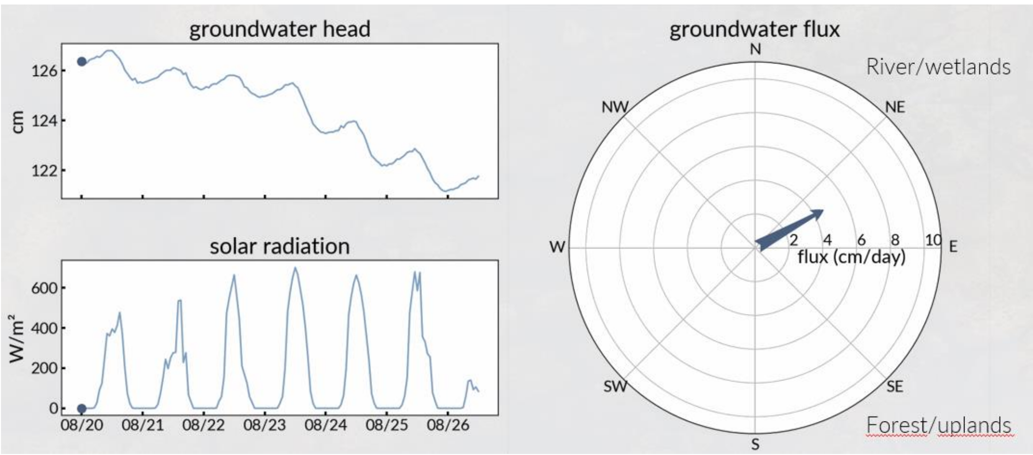

Fig. 2. Animated visualization of measured groundwater flux, head and solar radiation

Recalibration of the 3D transient groundwater model was performed in an automated way with FePEST. Calibration of the model with data from the vertical flux sensors lead to a substantial model improvement with almost identical model output fluxes compared to the observed ones.

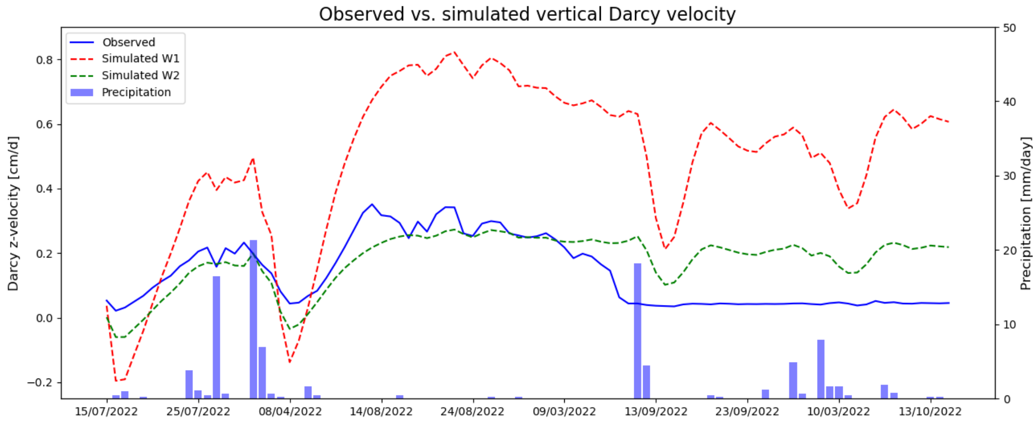

Fig. 3. Observed versus simulated vertical Darcy flux in Biebrza river

CONCLUSIONS

In conclusion, the results of our measurement showed large variations in groundwater flow on a small temporal scale, which were never measured before in the area with traditional methods, and contributed significantly to the model calibration improved. As such, the flux sensors provide new insights in groundwater – surface water interactions and can become an invaluable tool in ecohydrological studies worldwide, ultimately leading to more integrated management strategies to protect our remaining wetlands.

ACKNOWLEDGEMENTS

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SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

How to assess peatland drying using remote sensing?

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INTRODUCTION

Peatlands play a crucial role in preserving global biodiversity and climate regulation. Unfortunately, the area of wetlands in good ecological condition is dramatically decreasing (Hu et al., 2017). Therefore, developing an effective, fast, and objective method for assessing the state of peatland ecosystems represents a crucial challenge in nature conservation. Currently, remote sensing (RS) is considered one of the most useful methods for assessing the condition of wetlands (Guo et al., 2017). In this regard, in 2022 a peatlands condition assessment was carried out for two forest districts – Woziwoda and Tuchola, northern Poland, using RS methods. The study aimed to test the usefulness of different types of remote sensing data for assessing the dryness of peatland.

METHODS

A multi-sensor aerial platform, enabling the simultaneous acquisition of hyperspectral (HS), thermal infrared (TIR), and airborne laser scanning (ALS) data was used in the study. The data was obtained on July 20, 2022. Additionally, thermal data was collected during the night of July 20-21, 2022. The Crop Water Stress Index (CWSI) was also calculated based on TIR data and meteorological measurements. Field reference information was collected for 102 polygons.

During the fieldwork, 4 features describing peatland drying were determined for each polygon: moss drying, vascular plant drying, water levels in the peatland, and ground moisture. Each of these features was classified into four levels, where the first indicated no drying, and the fourth indicated a site that was completely dried out. The location, size, and botanical characteristics of the polygons were determined. Additionally, a combined index called the Multifactorial Peatland Drying Index (MPDI), was also created as a sum of all levels of peatland drying within the polygon. The range of the MPDI is then from 4 to 16. The initial phase of the analysis involved examining correlations between RS and field-collected data. Selected spectral indices (SI), daytime temperature (TIRd), nighttime temperature (TIRn), temperature difference between day and night (TIRdn), and CWSI were used as remote sensing input data for the analysis. The next step involved predicting peatland drying for the entire area of selected peatlands using machine learning methods. The use of various sets of input data for modelling a Multifactorial Peatland Drying Index was tested.

RESULTS and DISCUSSION

Among the analyzed features determining peatland drying, the highest correlation with RS data is observed for moss drying levels (up to r=0.84 with CWSI) and Multifactorial Peatland Drying Index (up to r=0.75 with TIRdn). Among the analyzed hyperspectral indices, the CAI (Cellulose Absorption Index) displays the strongest correlation with moss drying levels (r=0.80), LCAI (Lignin Cellulose Absorption Index) with vascular plant drying levels (r=0.54), and mNDWI (Modified Normalized Difference Water Index) with peatland dehydration levels (r=-0.61) and ground moisture (r=-0.66). Regarding thermal data-derived information, the TIRd, TIRdn, and the CWSI exhibit the strongest correlation with the characteristics determining peatland drying. In the case of MPDI modeling, the best results were obtained using the full dataset that includes hyperspectral and thermal infrared metrics. The R-squared value in this case is equal to 0.46. These results are promising, but further experiments are needed to improve them.

CONCLUSIONS

The initial results of Spearman correlation (p=0.05) analysis demonstrate that both the information derived from hyperspectral and thermal data exhibit a significant correlation with the features determining peatland drying. Notably, thermal data exhibit a stronger correlation with specific features. Through the application of advanced technologies, such as hyperspectral and thermal remote sensing, along with the currently intensively evolving analytical methods such as machine learning, it is possible to obtain objective and standardized information about the condition of peatlands. The results of this study can be used to identify the most desiccated areas, which can help take actions related to their protection and restoration.

ACKNOWLEDGEMENTS

The work was carried out within the the project “Protection of Valuable Ecosystems of Tuchola Forest” funded by the European Economic Area Financial Mechanism 2014-2021 within the framework of the Environment, Energy and Climate Change Programme MF EEA 2014-2021 “Implementation of Ecosystem Management Plans”

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SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

Change in Wetland Management over Time – Karolinów village in the Kampinos National Park

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INTRODUCTION

Kampinos National Park was created in 1959 for the conservation of the unique nature of inland dunes and wetlands. It covers over 385 km^2. It is protected as a national park (the highest form of protection in Poland), as a Natura 2000 site PLC140001 Puszcza Kampinoska and as an Important Bird Area PL084 by BirdLife International. Together with the Park's buffer zone it forms UNESCO MAB Biosphere Reserve "Puszcza Kampinoska".

Beginning in the 18th century, Kampinos wetlands were drained for agricultural use. In the 1970s the land buy-up programme was started and dedicated for nature protection. In the beginning of the 21st century the long term program of restoration was prepared. The restoration works started under the projects: Kampinos Wetlands (LIFE12 NAT/PL/000084, 2013-2019), Kampinos Wetlife (LIFE 19/NAT/PL/000746, 2020-2026) and MERLIN (Horizon 2020, GA No 101036337 2021-2025).

One of the areas where restoration is nearly completed is the former Karolinów village.

LOCATION AND LANDFORMS

Kampinos National Park is situated in central Poland on the Middle Mazovian Lowland in pre-valley of the Vistula River. It is located in the area of a hydrological node where big rivers: Bug, Narew, Wkra, Bzura flow into the Vistula river. Valleys of those rivers are ecological corridors of national and European rank.

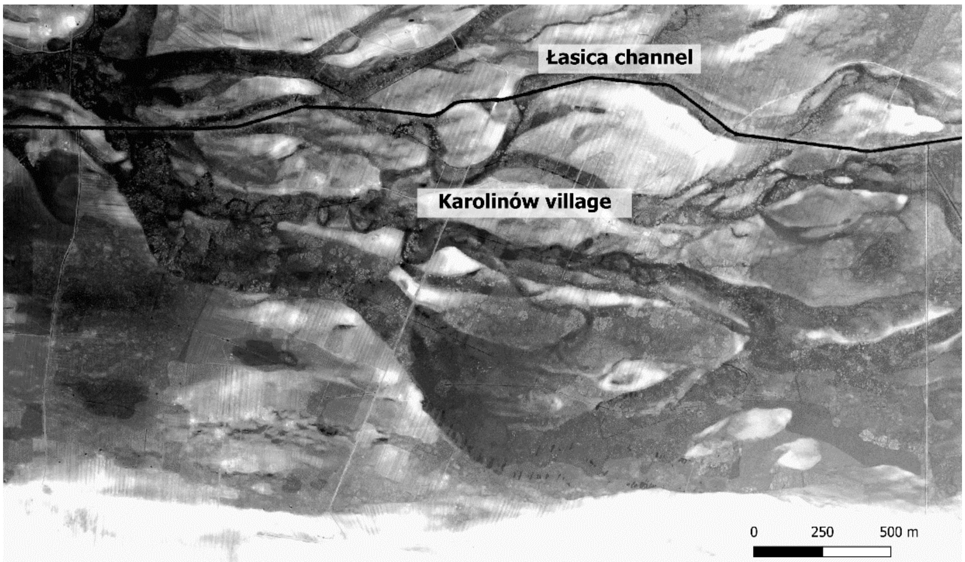

Fig. 1. Digital elevation model of surroundings of the Karolinów village. Visible braided and meandering lowerings. Water flow direction from east to west.

The area of Kampinos National Park has a structure of belts extending in an east-west direction, parallel to the Vistula River bed. This layout was created in the Late Pleistocene period. The dune areas are remnants of the highest Vistula terrace. The lowerings are former river beds which later changed into oxbow lakes and finally into marshes. The highest dunes reach up to 28 m of height. The south marsh belt consists of a few separated basins. The north belt forms one wide, nearly flat valley. The bottom of this valley is uneven in forms of braided and meandering lowerings - traces of flow of water in Pleistocene. Thereafter these lowerings were filled up with peat. Between them remain the small sandy hills up to 2-3 m high.

The Karolinów village was situated in western part of the north marsh belt on such elongated sandy hill system which is about 2000 m long.

CHANGES IN LAND USE AND DEVELOPMENT

Up to the middle of the 18th century most settlements were situated around Kampinos Forest. The demand for forest products caused people to increasingly penetrate the Forest. Two different communities gradually began to settle inside the area. At first they established temporary settlements, which later turned into villages. These were the so-called "hut-people" (named from poor huts in which they lived). The second community were colonists arriving here from the Netherlands and Germany called "Olenders." They were able to farm in areas that were often flooded. Such an "Olender" village was Karolinów, which was founded in the first half of the 19th century. The area around the village was deforested, divided into plots and used as meadows, pastures and arable land. Their boundaries ran perpendicular to the direction of natural water flow.

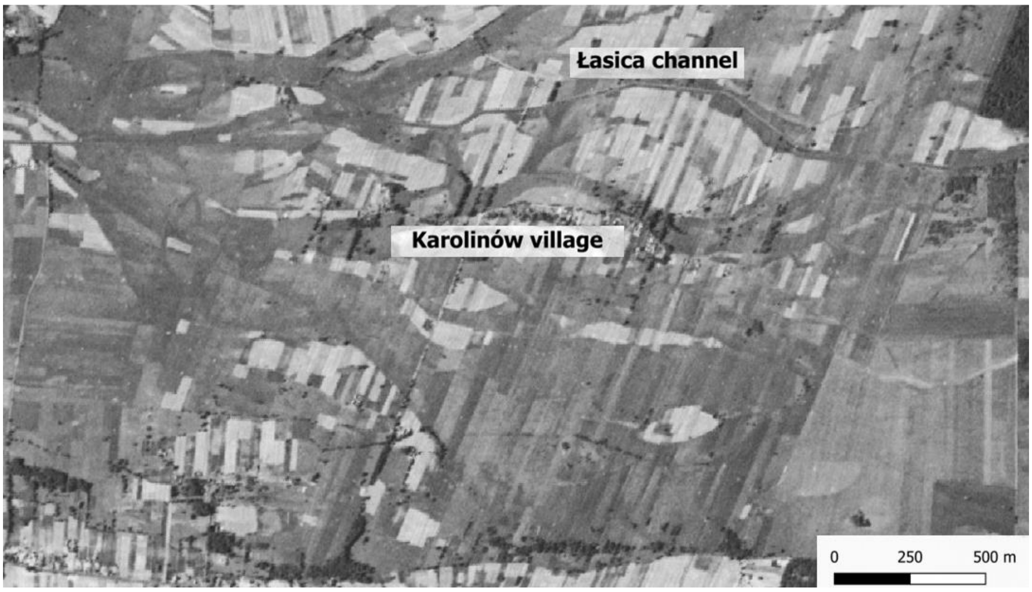

Fig. 2. Aerial photo of surroundings of the Karolinów village from 1969 (Corona imagery). Visible buildings of Karolinów village and the plots which are located in the N-S direction while the water flows east to west.

Drainage and peat degradation resulted in lowering of the ground level and fertility loss and so farming became very difficult.

Nature conservation was also impossible due to unregulated land ownership structure. In 1976 the decision was made by the Polish Government to buy up the land inside the Park for nature protection. Selling properties was voluntary, which caused a mosaic of private and state owned plots. The process of real estate purchasing still continues and now some villages are bought up nearly 100%. This is the case of Karolinów where private parcels cover less than 1% of the area. Depending on habitat, species and local situation they are either left for natural succession, forested or the active protection like water level increase or mowing is maintained.

SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

CHANGES IN WATER MANAGEMENT

During primeval times, before people settled inside Kampinos Forest there was no permanent river flowing through the marsh belts. These areas were predominantly drainless, only in western part small streams appeared in the wet seasons. The marsh belts were covered mainly with swamp forests (e.g. alder forests), low and transitional mires. In the middle of 18th century when people started to settle and use marshes for agriculture it became a necessity to accelerate the outflow of water. In the first stage they dug ditches to dry their fields. In the middle of the 19th century the plan of a systematic drainage system was implemented. Up to the 70s of the 20th century over 150 km of main channels and hundreds of kilometers of ditches were built. This system was maintained in working condition for the next 30 years. Marshes turned into mowed meadows, pastures and arable fields. Over time peats were desiccated and degraded and resulted in ground subsidence. Inventory, research and monitoring of water, soils, habitats, species as well as social structure were conducted in order to find the best scenario to improve the condition of marshes. In the lowerings near Karolinów deposits of shallow, maximum 1,70 m deep wood and reed peat were identified. In 2011, poorly developed, floristically poor patches of wet meadows from the *Calthion* association, typically developed patches of reed rushes from the *Phragmition* association and large sedge rushes from the *Magnocaricion* association were found here. These communities showed a significant degree of desiccation in places, which was manifested, among other things, by a significant share of the turf snail *Deschampsia caespitosa* in meadows and reed canary grass *Calamagrostis canescens* in rushes.

Since the buying up land program progressed, in some areas, such as Karolinów village, it became possible to increase ground water level and decrease outflow, especially in dry seasons, and reactivate processes of biomass accumulation, peat formation, and slow flow of water in braided meandering beds.

In the first step for restoration proper water conditions small, nature based solutions have been applied. In the vicinity of Karolinów four fords on the dirt road crossing smaller ditches were built. In the next step riffles on the main Łasica channel will be built. This enables filling with water lowerings surrounding the former village of Karolinów.

CONCLUSIONS

The successful restoration of nature and water retention in parts of the Kampinos National Park was made possible by the decisions to establish the national park 65 years ago. This was achieved thanks to land buyouts and the cessation of land drainage taken almost 50 years ago. It is only after such a long time that we are able to carry out technical measures to ensure the best possible hydration of wetlands and reactivate processes of biomass accumulation and peat forming. In addition, thanks to this their resilience to the effects of climate change increase. Perhaps transitional peatland habitats will be restored, common cottongrass and sphagnum species will return. We realize that if it were not for these decisions, it would be impossible to maintain and improve nature in such close proximity to the intensely expanding capital city of Warsaw.

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SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

The importance of environmental variables on yearly changes of reed stands at Lake Cerknica – a data mining approach

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INTRODUCTION

The Common reed (*Phragmites australis* (Cav.) Trin. ex Steudel) is a helophytic cosmopolitan grass. Common reed has become an integral part of wetland vegetation, thriving in slow-flowing and standing waters and in habitats such as fens (Čížková et al., 2023). At Lake Cerknica, an intermittent wetland, common reed plays a crucial role in providing various ecosystem services. Additionally, common reed stands provide a habitat for bird reedbed specialists (Kmecl et al., 2022). However, in recent years reed stands at certain areas of Lake Cerknica noticeably started to decline with water level data also showing an increase in extreme droughts and floods (Blatnik et al., 2024). The decrease in reed stands is likely a result of mowing events conducted in late summer. These concerns resulted in a shift in the management approach of reed beds, which is being implemented in the coming years.

While the extensive meteorological data dating back 70 years holds tremendous potential for explaining fluctuations in reed stands of Lake Cerknica, the dataset lacks the component of yearly reed stand information. Remote sensing holds significant potential for conducting long-term studies of reed stands. By leveraging the multispectral nature of remotely sensed datasets, calculation of vegetation indices solves the missing puzzle piece of past information regarding reed stands.

Our aim is to make use of remote sensing data, coupled with the extensive meteorological dataset, to acquire threshold values of environmental variables from which we can explain yearly changes in reed stands for the last four decades. Given the regular updates to these datasets, the robust predictive decision tree models generated through data mining algorithms have the potential to serve as valuable tools for decision-makers involved in the annual management of common reed at Lake Cerknica.

METHODS

Common reed stands at Trščenke, a reed-dominated area within Lake Cerknica along the main inflow, river Stržen, were monitored using satellite images from 1984 to 2023. We employed atmospherically corrected Landsat Collection 2, Level-2 data archives. Each year, an image corresponding to the peak greenness period for common reed, at Lake Cerknica, was selected. We then calculated the Modified Soil Adjusted Vegetation Index ($MSAVI_2$) for each image. The resulting raster images were clipped to the vector layer representing reed stands. Additionally, yearly differences in $MSAVI_2$ were computed, following the methodology proposed by (Singh, 1989).

The environmental data comprised water level data from the primary inflow, river Stržen, and temperature data obtained from a nearby climatological station. Environmental data was categorized into two groups: spring and summer data. From these categories, we derived 27 distinct environmental variables, which served as predictors for the data mining process.

The combined datasets formed the foundation for our data mining analysis. To conduct this analysis, we employed the WEKA software, using the M5P model tree classifier algorithm. This algorithm generates decision trees, wherein threshold values of the most significant predictors are identified. Terminal nodes of the decision tree contain linear models predicting the yearly change of $MSAVI_2$.

To compare real data against predicted values, we computed the 40-year average of $MSAVI_2$. Subsequently, we determined the percentage of yearly change relative to this 40-year average. To evaluate precision of each linear model, we conducted Welch's two-sample t-tests, comparing the actual percentage of change against the modeled percentage of change. We further compared the actual $MSAVI_2$ data with reed above-ground biomass (AGB) data collected between 2007 and 2021 which was also converted into annual percentage change based on its 15-year average.

RESULTS and DISCUSSION

The 40-year average $MSAVI_2$ at Trščenke was recorded at 0.494. The M5P data mining algorithm created a decision tree containing 12 different rules based on 5 different predictors with a total of seven outcomes. Each outcome is additionally defined with a linear model that predicts the yearly change of $MSAVI_2$ (Tab. 1). The most important established predictor was the previous year's $MSAVI_2$ value with a threshold of 0.467. Instances where values were below the threshold led to two different outcomes (LM1 and LM2) both indicating a significant yearly increase in $MSAVI_2$. The second most influential predictor was the minimum water level during summer months, set at a threshold of 173 cm. When the minimum water level exceeded this threshold, the model predicted an average decrease of 34.76 % (LM7), which closely matched the real data (Table 1). High water levels during summer negatively affect common reed growth in Lake Cerknica (Ojdanič et al., 2023), inhibiting early culm development due to reduced photosynthesis rates in submerged plants. On the other hand, when the minimum summer water level was below the threshold of 173 cm, the next important predictor was the average temperature of spring with a threshold value of 11.9 °C. In instances where the average spring temperature exceeded the threshold, a small decrease of 6.05 % was expected (LM6), however real data showed a greater decrease of 19.73 % (Tab. 1). The remaining important predictors were the maximum temperature during spring with a threshold value of 26.5 °C along with previous years $MSAVI_2$ with a threshold of 0.528. All results lead to predicted minimal change which in case of LM3 differs from real data. This highlights the flaw of the algorithm as it becomes less reliable when environmental factors lead to minimal changes, while significant changes were accurately predicted.

Table 1. The table presents the average real and predicted percentage of yearly change obtained from the linear models generated by the M5P data mining algorithm. Additionally, it includes the p-values resulting from the Welch t-test.

Linear model	average real change (%)	average predicted change (%)	p-value
LM1	37.14 ± 10.59	32.6 ± 8.08	0.407
LM2	18.77 ± 5.22	20.75 ± 3.91	0.689
LM3	10.68 ± 3.07	2.69 ± 8.44	0.018
LM4	1.88 ± 4.48	-3.77 ± 2.74	0.051
LM5	-3.31 ± 2.92	-2.6 ± 5.62	0.858
LM6	-19.73 ± 5.96	-6.05 ± 6.93	0.1765
LM7	-34.76 ± 11.91	-33.14 ± 12.01	0.764

When examining both the AGB and MSAVI2 data it is evident that common reed stands undergo significant annual fluctuations. The peak AGB was observed in 2009 marking the highest yearly increase according to the 15-year average. Interestingly, in the same year, the model predicted a substantial change (LM2) based on the preceding years $MSAVI_2$ values (Tab. 2). Notably, the most substantial reduction in AGB occurred in 2010. The model correctly predicted a significant decrease (LM7). Though the AGB and $MSAVI_2$ data correlates, it is not possible to predict the exact change in yearly productivity.

Table 2. The table presents the average yearly above-ground biomass. Additionally, the table includes the annual percentage of change of both the $MSAVI_2$ and above-ground biomass data.

Year	AGB (g/m^2)	AGB (%)	$MSAVI_2$ (%)
2007	548.1	/	/
2008	363.2	-41.7	-14.6
2009	953.4	133.0	26.6
2010	545.5	-91.9	-32.8
2011	308.3	-53.4	11.0
2012	623.6	71.0	22.6
2013	368.0	-57.6	-10.5
2014	290.7	-17.4	-32.4
2015	344.0	12.0	25.0
2016	302.7	-9.3	18.5
2017	366.9	14.5	-0.4
2018	390.0	5.2	-10.1
2019	215.3	-39.4	-31.3
2020	516.5	67.9	29.4
2021	521.2	1.1	9.0

CONNCLUSIONS

Acquired models robustly predict significant increases and decreases of common reed vitality. The models, however, contain a drawback as predicting minimal yearly changes is less reliable. Since decision makers regarding reed stands need to recognize years, where reed vitality drops significantly, the robust predictive model holds potential for a useful management tool.

ACKNOWLEDGEMENTS

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SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

Numerous environmental gradients shape plant community pattern in intermittent Lake Cerknica

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INTRODUCTION

Wetland vegetation in different habitats of intermittent Lake Cerknica was studied. The mentioned lake has been studied for decades, but new research questions remain. Gaberščik et al. (2018) found a great diversity of plant communities and plant species along the hydrological gradient on Lake Cerknica. We have focused on differences in the structure of marsh vegetation with dominant *Phragmites australis, Phalaris arundinacea* and *Carex elata*. Besides, two plant communities with dominant *Schoenus nigricans* and *S. ferrugineus* characteristics of fens were studied. The main questions were 1) how these vegetation types differ in plant species composition and diversity and 2) which site conditions drive the structure of the studied vegetation significantly and differ between the sites.

METHODS

Vegetation was analyzed according to Braun-Blanquet (1964) method. Along with the plant composition of the selected plots, soil samples were collected and analyzed to reveal the soil properties of these sites. Compound soil samples were dried, homogenized, and analyzed for pH, conductivity, plant-available phosphorous and potassium, total nitrogen and organic carbon, exchangeable basic cations, and content of the carbonates. Cluster analysis was performed to classify the plant stands (Euclidean distance, UPGMA). Multivariate analyses of the vegetation records and results of soil analyses were performed with CANOCO v.5.

RESULTS and DISCUSSION

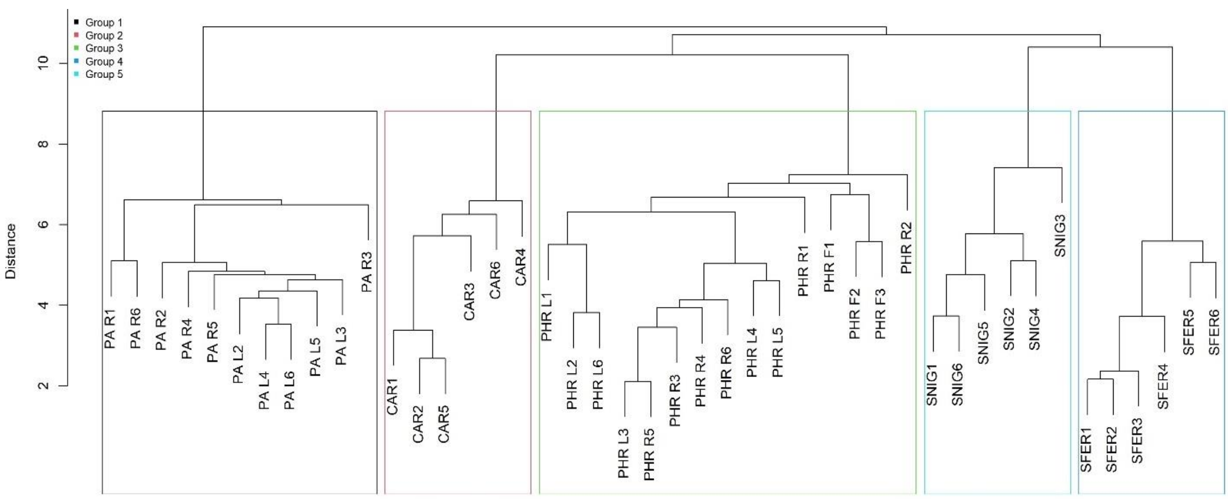

Fig. 1. Result of the clustering according to the similarity of the plant stands calculated with Euclidean index (UPGMA method). PA R – *Phalaris arundinacea* "riparian" stands; PA L – *P. arundinacea* "littoral" stands; PHR R – *Phragmites australis* "riparian" stands; PHR L – *P. australis* "littoral" stands; PHR F – *P. australis* "fen" stands; CAR – *Carex elata* stands; SNIG – *Schoenus nigricans* stands; SFER – *S. ferrugineus* stands.

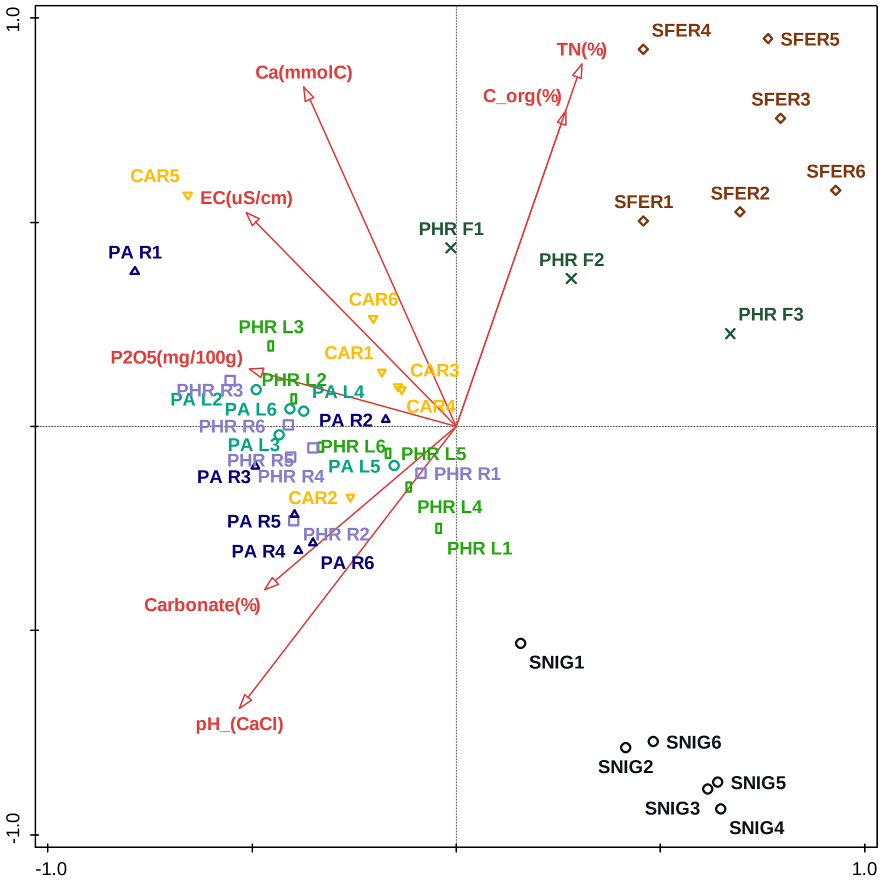

Fig. 2. Biplot obtained on the base of CCA. Only the factors that significantly shaped the plant composition are displayed. Species data were log-transformed.

Table 1. Soil properties that significantly explain the floristic composition of the analyzed wetland vegetation and proportions of the total variance explained by specific factors.

Factor	Explains [%]	p
TN (%)	11.5	0.002
Ca^{2+} (mmol C/100g)	9.3	0.002
Available P (P_2O_5 mg/100g)	4.8	0.002
organic C (%)	4.7	0.012
pH (in CaCl2)	3.8	0.002
conductivity (uS/cm)	3.7	0.026
Carbonate content (%)	2.5	0.056

The cluster analysis divided recorded plant stands into three groups (Fig. 1): one with dominant *Phalaris*, the second with *Phragmites*, and the third was fen vegetation, where dominant species was either *S. nigricans* or *S. ferrugineus*. The most important soil parameters shaping the vegetation composition were the content of total nitrogen (TN) and exchangeable Ca, which explained 20% of the vegetation variability. Other significant factors were the content of plant-available P, organic C, pH, conductivity, and carbonate content. They cumulatively explained 40.3% of plant species composition. The distribution of the 44 plots along these gradients is evident (Fig. 2), and mostly enables clear detachment of specific plant communities. These results match the results of cluster analysis (Fig. 1).

The vegetation type with the highest number and diversity of plant species were stands with *Phragmites* on fen sites. The common reed here does not form so thick stands as in the riparian and littoral sites, allowing lower, less competitive plant species to thrive. These soils on fen sites have significantly lower pH than the other two groups.

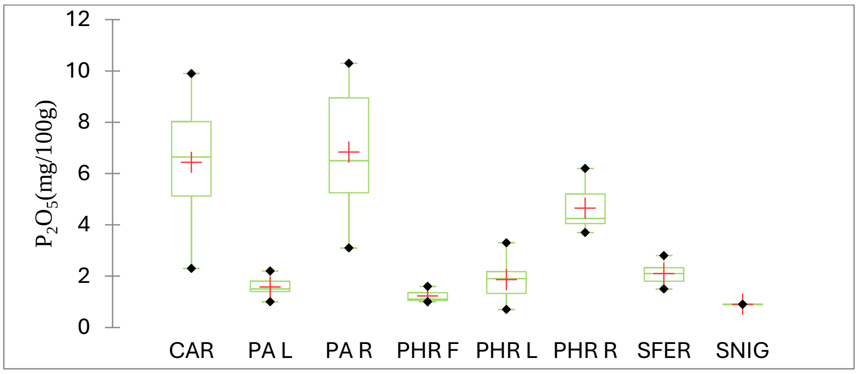

Fig. 3. Box-whisker plot of the concentrations of plant-available P in the soil measured in specific vegetation types.

The sites of the riparian and littoral reeds differ in the amount of available P in the soil, which is significantly higher in riparian sites than in littoral as well as fen sites (Fig. 3), which aligns with Ojdanič et al. (2023), who claim that more favorable conditions at the riparian site benefited the productivity of *Phragmites*. The content of available P is confirmed as a significant difference between the riparian and littoral *Phalaris* stands, which also thrive on the sites with a significantly higher content of carbonates. Available P content is also significantly higher in tall sedges than in fens with *S. ferrugineus* and *S. nigricans*, respectively.

CONCLUSIONS

A great diversity of vegetation types and plant species on the intermittent lake Cerknica results from many gradients and their spans that shape the distribution of plant communities and the species they are hosting.

ACKNOWLEDGEMENTS

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SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

Wetland area assessment in North Macedonia

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INTRODUCTION

Positioned amidst predominant (non-wet) forests and pastures, wetlands in North Macedonia hold a distinctive status owing to their significant provisioning of diverse ecosystem services. Even so, in recent times, they have received insufficient attention by researchers and decision-makers. Various databases (e.g. European Environmental Agency databases, Mediterranean Wetlands Observatory, Global Peatland Database etc.), provide wetland-related spatial data, nevertheless, notable spatial data gaps endure, particularly regarding high-altitude mires. Additionally, clarity is lacking regarding additional wetland information such as their heterogeneity or condition. As a consequence, the precise spatial extent remains inadequately assessed, contributing to their oversight by both practitioners and policymakers.

The aim of our study was to create the first comprehensive map of wetlands in the country in order to assess their spatial extent, distribution and characteristics. Additionally, potential wetland areas were investigated in order to provide guidance for future studies.

METHODS

Available spatial data were collected and additional digitalisation was conducted in order to fill spatial data gaps. Additional mapping was done by visual interpretation and manual digitalization by using topographic maps, national land use cadastre (2002-2004) including Orto-photo (2017), combined with Google Earth Pro satellite imagery (2016 to 2022 sensing date). For wetlands, especially peatlands not detectable on satellite imagery, field spatial records were used from available data sources (projects, studies, papers, personal records etc.).

Upon completion of the map, a set of criteria was discerned, focusing on the paramount aspects of wetlands, namely soils, water, and vegetation. Subsequently, the riparian wetland area was extracted, while a non-hierarchical multivariate clustering method (K-means) was employed to systematically categorize the other wetland area.

For the analysis of areas with high wetland potential, several datasets were used and updated or modified (water and wetness 2018 layer (EEA 2020), national map of hydrogeological potential (1977), drainage channels layer (Hristovski et al. 2020)). Mapping and processing was performed using ArcGIS 10.7 and ArcGIS Pro.

RESULTS and DISCUSSION

Spatial distribution, extent and characteristics of wetland area

Integration of available data, alongside digitalization and processing efforts, resulted in the creation of the first comprehensive map depicting wetland areas with current wetland vegetation in North Macedonia (Fig. 1). Initially, the mapping focused on habitats to facilitate the development of a national habitat map (Hristovski et al, 2024). However, utilization of EUNIS structured classification system somewhat obscured wetland information. Therefore, our map endeavors to delineate various wetland types, encompassing reedbeds, wet meadows, wetland forests, mires, springs, temporary lakes and ponds, inland salt marshes, rice fields, and other unclassified wetland areas. According to our results, the current wetland extent is 382.92 km^2 or 1.5% of the country area. 186.40 km^2 refers to riparian forests, while 196.52 km^2 to other wetland area.

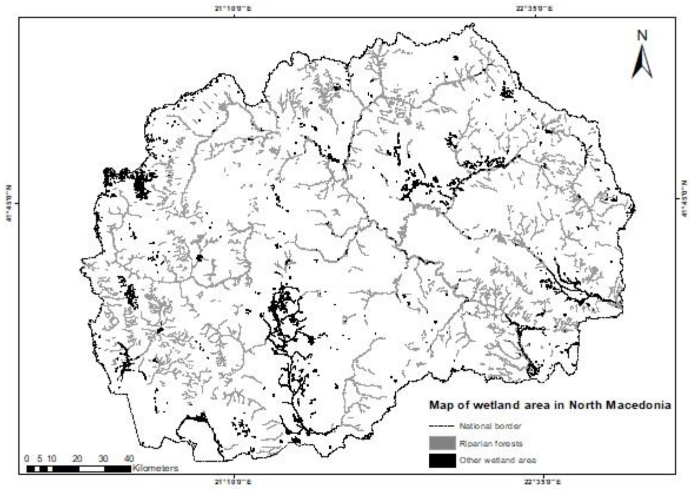

Fig. 1. Map of wetland area in North Macedonia

Defining wetland categories based only on wetland habitat types can be limiting in potential use of the data. Therefore, it is crucial to have more holistic approach and encompass all aspects of wetland ecosystems, including water, soils and vegetation. In this context, we identify riparian forests as a distinct wetland category prevalent across the country with high heterogeneity of environmental variables. Optimised pseudo-F statistics of the other wetland area highlighted two clusters based on national-scale environmental data (altitude, soil types, geology type, vegetation type, hydrology, water and wetness status, precipitation, temperature and slope), with altitude being statistically most important variable. Considering this, we can clearly divide the wetland area in lowland and mountainous (Fig. 2).

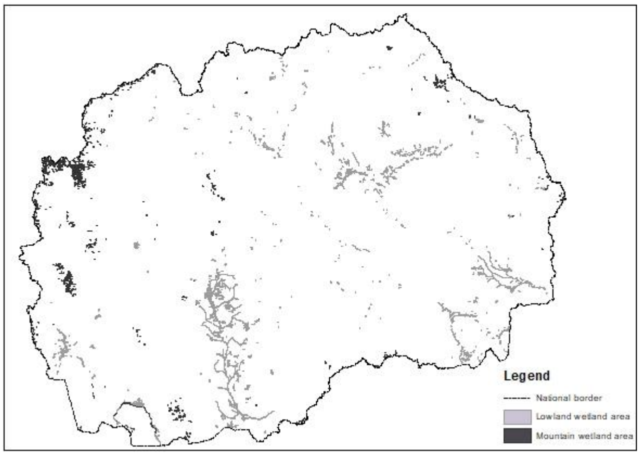

Fig. 2.Sparial distribution of the wetland area divided in two clusters based on environmental data

Analysis of areas with high wetland potential

The comprehensive representation of different wetland habitat types in our map led to restrictions in relation to areas without current wetland vegetation, in particular the omission of potential peatland areas. To address this, we conducted initial analyses to identify high-potential wetland areas. Agriculture intensified in North Macedonia post-World War II, leading to the construction of drainage systems (Fig. 3 A), particularly impacting lowland wetlands also due to malaria concerns. Mapping efforts using historical topographic sources were hindered by data availability constraints pre-1950s. However, the national hydrogeological potential map from the 1970s (Fig. 3 B) offers valuable insights, aligning well with recent data from the Water and Wetness (2018) layer (Fig. 3 C). Synthesizing this data with the data presented in Fig. 1 allows identification of high-significance areas in wetland potential (Fig. 3 D). Nevertheless, it should be noted that this mainly refers for the wetland area in the lowlands, while high-altitudes differ in land use but are also represented with mainly small-sized scattered wetland areas.

SESSION IV - FLOW WITH THE WATER: HYDROLOGY AND MONITORING

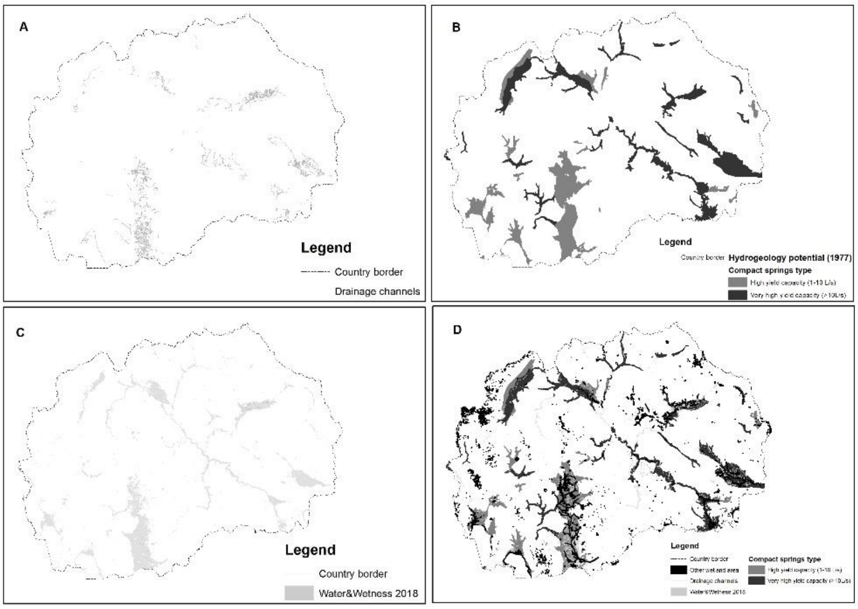

Fig. 3. Analysis of areas with high wetland potential.

CONCLUSIONS

Wetlands occupy 1.5% of North Macedonia (382.92 km^2), including riparian forests (186.40 km^2) and other wetlands (196.52 km^2). Relying solely on vegetation types may limit data use, thus more holistic approach including environmental data was essential. The current wetland map incorporates the first high resolution data for high-altitude mires underscoring the urgency for further mapping in the Balkan area, particularly addressing these unique peatlands. Historical mapping constraints were mitigated by integrating hydrogeological and recent wetness data, revealing areas of wetland potential, primarily in lowlands. These results should guide future research for collecting ground truth data in order to better estimate the lowland wetland area and thus help future restoration efforts.

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SESSION VI - INTO THE FUTURE: PREDICTING AND PLANNING

The photosynthetic capacity of bog cranberry (*Vaccinium oxycoccos* L.) and *Sphagnum* moss (*Sphagnum* spp.) increases with warmer late winter and early spring: A climate manipulation study

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INTRODUCTION

Northern peatlands are a specific ecosystem that plays an essential role in the global carbon cycle, disproportionally larger than their global coverage (Antala et al., 2022). Peat moss (*Sphagnum* spp.) and ericoid shrubs like bog cranberry (*Vaccinium oxycoccos* L.) are some of the most common plant functional groups (PFGs) found in the northern peatlands. Both PFGs can be characterized as evergreen, which means they start to be photosynthetically active as soon as the conditions in spring become favourable, without the need to grow leaf first (Buttler et al., 2015; Chiapusio et al., 2021). Increasing global temperature undoubtedly impacts the peatland vegetation spring phenology and the start of photosynthetic activity (Antala et al., 2022; Peichl et al., 2015). However, it is unclear how different PFGs react to the same increase in temperature and what mechanisms are behind the specific reactions of PFGs' photosynthetic apparatus. Because such knowledge is important for further refinement of peatland or global carbon cycle models, we performed an experiment aiming to clarify the impact of late winter and early spring warming on the photosynthetic capacity of bog cranberry and peat moss.

METHODS

The data was collected at the experimental station localized in Rzecin peatland (52◦'45'41" N, 16◦18'35" E, 54 m a.s.l.), western Poland, where the warming and reduced precipitation experiment was established in 2017. A detailed description of the site is provided by Antala et al. (2024). The plots of control (C) and warming (W) conditions of the CR (dominant graminoid is beaked sedge; Carex rostra Stokes) site were used for this study. Warming of the plots was induced by the combination of open-top chambers and 100 W infrared heaters switched on for nighttime only (Antala et al., 2024).

The temperature was measured next to every plot 30 cm above the surface by HygroVue5 thermohygrometers (Campbell Sci., USA) and recorded every half hour on datalogger CR1000 (Campbell Sci., USA; (Antala et al., 2024). The summary of thermal conditions during winter and the first two weeks of meteorological spring is presented in Table 1.

The measurements by FluorPen FP 110/D (Photon System Instruments, Drasov, Czech Republic) with detachable dark adaptation clips were done on 13th March 2024. 5 leaves of different bog cranberry plants and 5 plants of Sphagnum plants, irrespective of species, were measured by OJIP and NPQ3 protocols provided by the manufacturer. The measurement light was set to 85%, while the actinic light for the NPQ3 protocol was 300 μmol m-2 s-1. The wavelength of the used light was 455 nm. All measurements were done after at least 25 minutes of dark adaptation on a cloudy day. The maximum quantum yield of photosystem II photochemistry (ϕPO) was calculated from data from both protocols. The actual quantum yield of photosystem II photochemistry (ϕP), the quantum yield of light-induced energy dissipation (ϕNPQ), the quantum yield of light-independent energy dissipation (ϕNO), and non-photochemical quenching of maximum fluorescence (NPQ) were calculated from NPQ3 protocol. The quantum yield of electron transport at time 0 (ϕEo), and the efficiency of electron transport beyond plastoquinone (Ψo) were determined from OJIP measurements. All parameters were calculated based on Kalaji et al. (2017).

Table 1. Average, absolute daily minimal and average daily minimal temperatures of control and warming plots during the period of 4, 2 and 1 month and 2 and 1 week before the chlorophyll fluorescence measurements (13th March, 2024)

	Control			Warming		
	average	absolute min	average min	average	absolute min	average min
4 months	2.6 °C	-11.9 °C	1.8 °C	2.8 °C	-14.8 °C	1.9 °C
2 months	4.1 °C	-5.4 °C	3.0 °C	4.5 °C	-7.4 °C	3.3 °C
1 month	5.6 °C	-5.4 °C	3.6 °C	6.3 °C	-4.2 °C	4.2 °C
2 weeks	5.4 °C	-5.4 °C	2.8 °C	6.4 °C	-4.2 °C	3.4 °C
1 week	4.1 °C	-5.4 °C	0.2 °C	5.2 °C	-4.2 °C	1.0 °C

RESULTS and DISCUSSION

The increased temperature clearly impacted the ϕPO of both PFGs with a higher increase of ϕPO due to W for bog cranberry than for peat moss (Fig 1A). As evergreen plants were found to downregulate their photosynthetic capacity during winter and then upregulate it back to normal without apparent damage, our results indicate the phenological shift of plant physiology due to warmer conditions (Gilmore and Ball, 2000). Interestingly, no significant differences in the ϕP measured at 300 μmol m^{-2} s^{-1} were found (Fig 1B).

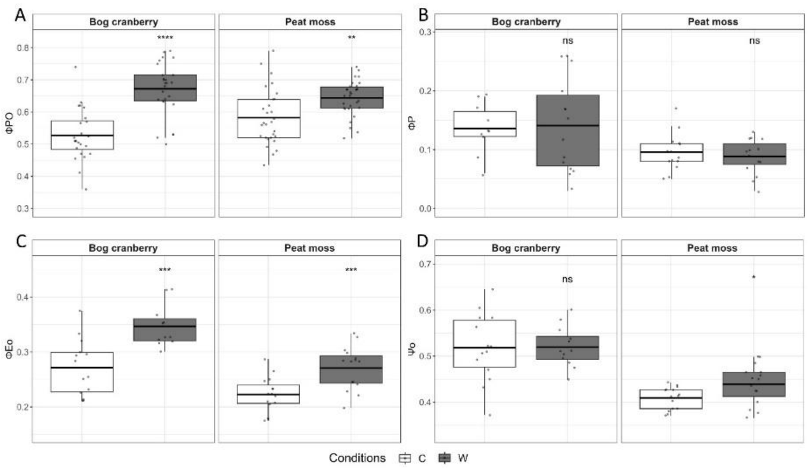

Fig. 1. The maximum quantum yield of photosystem II photochemistry (ϕPO; A), the actual quantum yield of photosystem II photochemistry (ϕP) at 300 μmol m-2 s-1 (B), The quantum yield of electron transport at time 0 (ϕEo; C), and the efficiency of electron transport beyond plastoquinone (Ψo; D) of bog cranberry and peat moss subjected to control (C) and warming (W) conditions. The thick line in the boxplot represents the mean, while the points represent single measurements. “ns” non-significant, * <0.05, ** <0.01, *** < 0.001, **** <0.0001.

ϕEo of bog cranberries and peat moss increased by 31% and 22%, respectively, due to warmer conditions (Fig. 1C). These results further prove the higher readiness of both species to use the trapped energy for photochemical reactions. However, while Ψo of peat moss increased in W condition, it remained stable for bog cranberry (Fig. 1D).

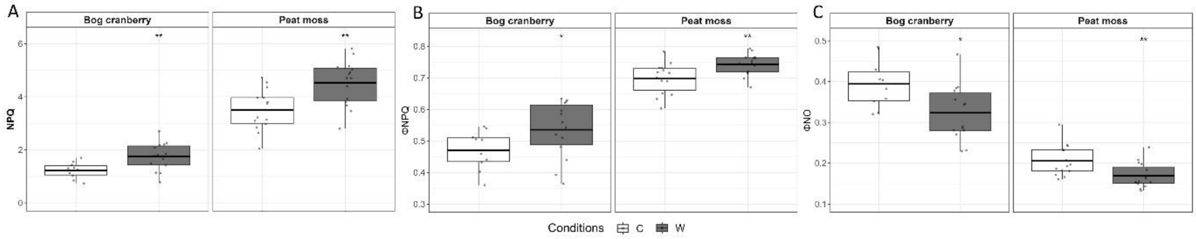

Fig. 2. Non-photochemical quenching of maximum fluorescence (NPQ; A), quantum yield of light-induced energy dissipation (ϕNPQ; B), and quantum yield of light-independent energy dissipation (ϕNO; C) measured at 300 µmol m-2 s-1 from bog cranberry and peat moss subjected to control (C) and warming (W) conditions. The thick line in the boxplot represents the mean, while the points represent single measurements. * <0.05, ** <0.01.

A significant increase of NPQ was observed for both studied PFGs (Fig. 2A). A better understanding of NPQ can be reached by examining its single components, ϕNPQ and ϕNO. Both PFGs exhibit increased ϕNPQ and decreased ϕNO in warmer conditions (Fig. 2B, C), which increase NPQ. The differences between PFGs are more pronounced than differences within PFGs caused by higher temperatures. Higher ϕNPQ and, at the same time, lower ϕNO of peat moss compared to bog cranberry indicate that peat moss is able to quickly react on even shorter periods of favourable conditions during winter by increased rates of photochemistry, while bog cranberries utilize the strategy of more constant protection of photosynthetic machinery that relaxes comparatively slower (Bassi and Dall'osto, 2021; Kalaji et al., 2017). Therefore, peat mosses are a major contributor to the peatland vegetation carbon uptake during the beginning of vegetation season, as found also by Peichl et al. (2015).

CONCLUSIONS

In this work, we showed that 0.7-1°C warmer late winter and early spring lead to a significant increase in ϕPO of bog cranberries and peat moss. This increase is regulated by plants' decreasing dependency on ϕNO and increased capacity of ϕNPQ. Moreover, we demonstrated that different PFGs rely on different strategies of photosynthetic apparatus protection during winter. These findings help to understand the impact of ongoing climate change on some of the most abundant plants in northern peatlands and shed light on physiological changes happening in these plants during the winter and spring months.

ACKNOWLEDGEMENTS

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SESSION VI - INTO THE FUTURE: PREDICTING AND PLANNING

Multiple environmental factors interact to affect wet grassland CO_2 and CH_4 emissions

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INTRODUCTION

Greenhouse gases (GHG) emissions result from biological processes influenced by the environmental conditions at the particular site. Carbon dioxide (CO_2) is produced by plants, microbes and animals while only soil microbes produce methane (CH_4) and nitrous oxide (N_2O). Site hydrology is the most influential abiotic factor affecting all GHG emissions (Oertel et al. 2016). CO_2 emissions tend to decrease with higher water levels while both CH_4 and N_2O emissions usually increase (Zhao et al. 2020). Other factors, such as soil type and nutrient content, also greatly affect GHG emissions. All GHG emissions are also strongly affected by plants. About half of all CO_2 emissions originate as plant respiration. Microbial respiration is affected by the quality and quantity of plant inputs, as plant litter or root exudates, which increase the availability of organic substances to the microbes (Jones et al. 2009; Pokhalar and Chang 2019).

GHG emissions are variable over time and space since they result from many biological processes. These effects are still not well understood nor easily quantified. Many past studies focused on the effects of individual factors, but often reached contradictory conclusions (Brechet et al. 2019). In a past field study, we found that nutrient addition accelerated nutrient fluxes in two wet grasslands, one with organic and the other on mineral soils, but nutrients interacted with site hydrology to influence these processes (Picek et al. 2008). Therefore, multiple environmental factors seemed to interact to affect the ecological functioning of these wet grasslands, however the importance of these factors could not be disentangled in the field.

We established a mesocosm to conduct a multifactorial study to determine how these factors, either singly or interactively, affected plant and soil parameters and how these then influence GHG emissions. We expected that GHG emissions would be the most affected by water level, followed by soil type and nutrient level. Further, these effects would differ between vegetated and un-vegetated conditions.

METHODS

We established the mesocosm in 2009. The mesocosm consisted of three treatment factors (soil type = organic, mineral (Cambisol); water level = 15 cm below the soil surface; saturated but not flooded; nutrient addition = un-fertilized, 300 kg NPK * ha^{-1} * yr^{-1}) in a full factorial design. Treatment combinations were randomly assigned to basins into which were placed pots with plants of *Carex acuta* (rhizosphere conditions) or without plants (bulk soil). Samples were taken in 2013, five years after mesocosm establishment. Plant and soil samples were collected four times during 2013 (March, May, July, October) to determine seasonal effects on the measured parameters (plant biomass, soil physico-chemical traits, soil microbial density). GHG emissions were measured monthly using the static chamber method (Livingston and Hutchinson 1995) in randomly selected pots which were fitted with collars on the outside of the pots. GHG were sampled from May to October.

Generalized linear mixed models (GLMM) were used to test the treatment effects on the collected plant and soil parameters, following natural logarithm or square root transformations of the data if needed. The GLMM tests were run in R v 4.0.5 using the nlme package (Pinheiro et al. 2016). The experimental treatments were the fixed effects while time was a random effect. Principal components analysis (PCA) and redundancy analysis (RDA) were conducted in PC-

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ORD v. 7.0 (McCune and Mefford 2018) on a separate dataset to determine the effects of the experimental treatments on GHG emissions. Regression analyses were then run in Statistica v 14.0 (TIBCO Software Inc, 2020) to determine which plant and soil parameters most correlated with GHG emissions. The regression and multivariate analyses were conducted separately on vegetated and un-vegetated datasets.

Finally, structural equation models (SEM) were developed for both vegetated and un-vegetated samples to determine the possible connections between the treatment factors, measured parameters and GHG emissions (Grace 2006). The SEMs were constructed using AMOS v. 21.

RESULTS and DISCUSSION

All environmental factors affected the measured plant, soil and GHG parameters, both singly and interactively. Most parameters reached their maxima in organic, fertilized conditions, except for soil pH (mineral, unfertilized soil) and CH_4 (unfertilized), as noted by PCA and RDA analyses. Higher water level decreased CO_2 emissions while increasing those of CH_4. Nutrient addition had a direct, positive effect on plant biomass and production, which was most related to GHG emissions, with plant respiration being the largest contribution to CO_2 emissions. Plant litter and root exudate inputs supplied soil microbes with organic substrates, thereby supporting microbial growth and increasing microbial respiration and CH_4 production.

Almost all parameters showed a distinct seasonality, except for soil pH, microbial biomass nitrogen (N_{mic}) and bacterial abundance. GHG emissions were low in the cooler parts of the growing season with the highest rates at the time of peak plant biomass in July and August, again showing the strong connection between plant growth and GHG emissions.

SEMs for vegetated and un-vegetated samples illustrate these direct and indirect connections (Fig. 1, 2). In vegetated conditions, nutrient addition directly promoted plant biomass which then affected CO_2 emissions. Water level directly increased CH_4 emissions but decreased bacterial abundance, while soil type affected the Soil Traits latent variable (Fig. 1). Several plant-soil feedbacks indicate that increased C and nutrient inputs from plants (litter, root exudates) would greatly affect the soil component. Water level also directly affected the GHG emissions in the un-vegetated SEM (Fig. 2). All three environmental factors indirectly affected CO_2 emissions by influencing NO_3^- content.

CONCLUSIONS

Our results indicate the importance of multiple factor interactions. Additive relationships seem to govern the biotic components (plant biomass, microbial abundance) while factor interactions were more important in affecting soil parameters and GHG emissions. Such interactions could have large consequences for managing and/or restoring wet grasslands and other wetland habitats. Also, while CH_4 emissions were low and usually associated with plants, emissions were greater from un-vegetated than vegetated samples in mineral soil. Therefore, the formation of bare patches resulting from the activities of animals or agricultural practices could result in these patches becoming CH_4 emission hotspots.

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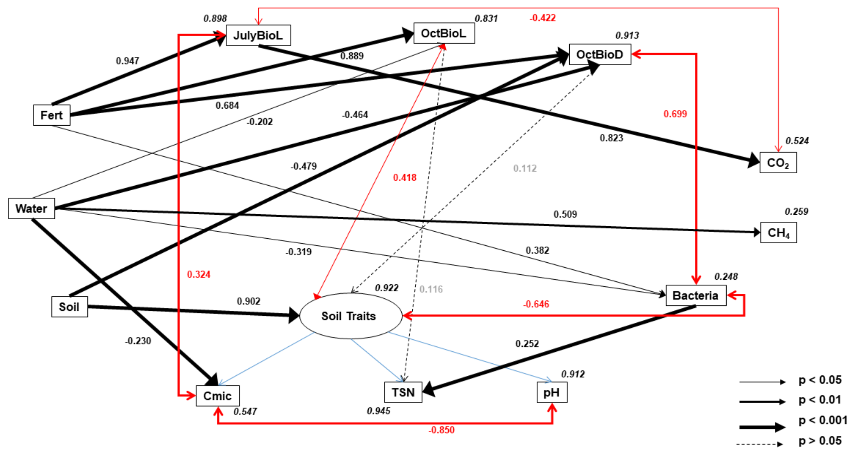

Fig. 1. Structural equation model (SEM) for the vegetated treatment. Arrow width indicates degree of significance. Black arrows = one-way effects; red arrows = two-way effects. BioL = live plant biomass; BioD = dead plant biomass; TSN = total soluble nitrogen; C_{mic} = microbe biomass C. The model was admissible. Model fits: χ^2 = 51.444 (p = 0.151); RMSEA = 0.099 (p = 0.223); Akaike information criteria (AIC) = 123.444.

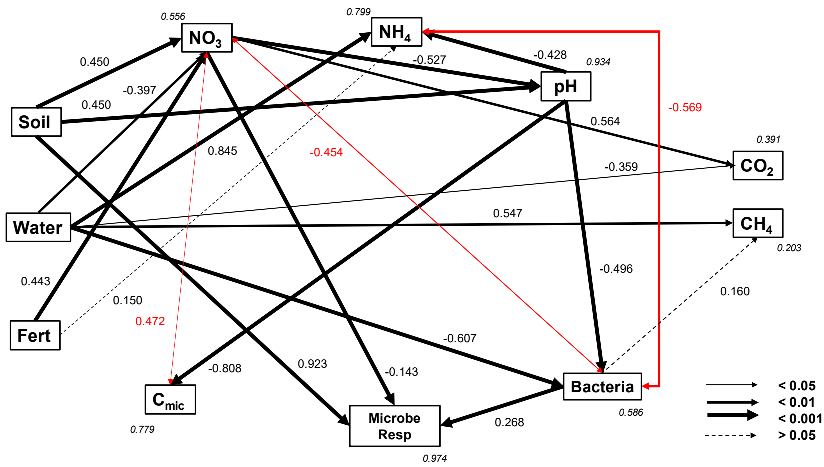

Fig. 2. Structural equation model (SEM) for the un-vegetated treatment. Arrow width indicates degree of significance. Black arrows = one-way effects; red arrows = two-way effects. Microbe Resp = microbial respiration; Cmic = microbe biomass C. Model was admissible. Model fits: χ2 = 41.272 (p = 0.183); RMSEA = 0.096 (p = 0.254); Akaike information criteria (AIC) = 105.272

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SESSION VI - INTO THE FUTURE: PREDICTING AND PLANNING

Notes on ecological factors shaping vegetation diversity of mires in Norwegian Finmark

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INTRODUCTION

Undisturbed peatlands (mires) play an extremely important role for all life on Earth. They are perfect stores of water and carbon, stabilizing the Earth's climate. They are also home to many endangered species. In Europe, most peatlands have been destroyed by humans. The most undisturbed peatlands are found in the northernmost parts of our continent, for example in Finnmark in Norway. So far, there have been no detailed, large-scale studies of peatland flora and vegetation in this region. Isolated data on the distribution of some mire species come from herbarium material from the 19th century. In the second half of the 20th century, surveys were made of the vegetation in Finnmark, including wetlands (e.g. Vorren 1979a, Vorren 1979b). However, these studies were either characterized by a small number of samples or were carried out on a very small area. I therefore decided to carry out a study that would describe the mire vegetation of Finnmark and its habitat preferences in detail.

METHODS

Study area

I began my research on the mires of Finnmark with preparatory work. I collected the results of previous research on the vegetation of the northern part of Norway and, with the help of freely available geological maps and aerial photographs, selected potentially interesting objects (mires) in the field.

Fieldwork

During the fieldwork I visited pre-selected sites. At each investigated site I took a square shaped relevee (25 m^2) in extended Braun-Blanquet scale including both vascular plants and cryptogams. If the vegetation of the surveyed site was diverse I collected more than one relevee (sample) per site.

Within each of the relevees I measured pH and EC in situ, both from the surface water, which probably better reflects the conditions for bryophyte development and from the top 15 cm soil porewater, which might better reflect the conditions for the vascular plants. I also collected porewater from the same top soil layer for determination of selected elements.

Data analysis

After the fieldwork additional data on climate (from CHELSA database, Kager et al. 2018) and elevation (from global GLO-30 Copernicus DEM) were obtained with the use of QGIS software for each of the sampling plots. Collected porewater samples were analyzed with ICP-MS for Ca, Mg, Na, K, Si, S, P, Fe, Sr, B, Ba, Zn, Al, Mn, Cu, Li, Cr, Ti, As, Cd, Co, Mo, Ni, Pb, and V. The vegetation and environmental data were then analyzed with JUICE (build-in TWINSPAN algorithm, Tichý 2002) and R software (vegan package, Oksanen et al. 2022). As I am still in the process of identifying cryptogams, I have used only vascular plant data for the results presented here.

RESULTS and DISCUSSION

An Unsupervised TWINSPAN algorithm divided 104 relevees into 7 groups. The general characteristics of the vascular plant composition suggest that groups no. 1 and 2 are probably relatively dry rich fens, group no. 3 represents very acidic poor fens, groups no. 4 and 5 are similar and represent intermediate fens, and group no. 6 includes moderately rich but waterlogged fens. Group 7 was represented only by two relevees representing an unique type of arctic-alpine rich fens dominated by *Carex saxatilis*.

In the DCA diagram based on the vascular plant composition of the relevees, clear separation of groups 1, 2 and 6, and to some extent also 3, and a slight differentiation of groups 4 and 5 is visible. Addition of strongly significantly ($p< 0.01$) related environmental variables to the DCA diagram proves a very multidimensional character of the vegetation differentiation, with both local (pH, EC, and probably also waterlogging), regional (availability of selected elements related to the geology) and macroecological (climate) factors shaping the diversity of mire ecosystems of Finnmark. The main gradient of vegetation differentiation represented by the first (horizontal) axis seems to be, unsurprisingly) correlated with the pH of the sites. But at the same time it seems to reflect the climatic gradient with warmer conditions at its left end (e.g. *Drosera anglica* was absent from the colder regions). The second (vertical) gradient axis probably indicates the moisture content of each site (at the bottom of the graph there are species associated with habitats with high groundwater levels, e.g. *Comarum palustre* and *Equisetum fluviatile* or *Salix lapponum*, and at the top there are taxa found in non-flooded sites, e.g. *Sausarea alpina*, *Thalictrum alpinum* or *Tofieldia pusilla)*. However this gradient seems to represent also to some extent base saturation (with more mineral-rich sites at the top) and altitude and summer precipitation (with higher lying and wetter sites at the bottom). These differences between groups were further explored by between-groups comparisons, which indicate that for example water conductivity clearly separates groups 1 (very high conductivity), 2 (high conductivity), 3 (very low conductivity) and 4 and 5 together (moderate conductivity). In case of climate vegetation of group 1 clearly prefers areas with relatively high average annual temperatures.

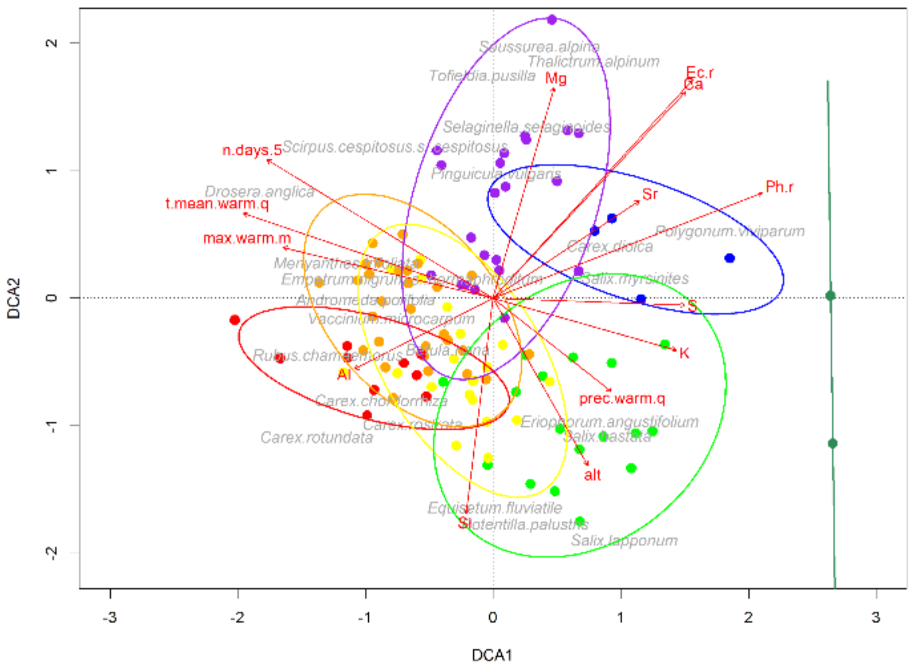

Fig. 1. DCA analyses on the vegetation. Colors represent TWINSPAN groups: blue – group 1, violet – group 2, red – group 3, orange - group 4, yellow – group 5, light green – group 6, dark green – group 7. Red arrows represent significantly ($p<0.01$) correlated related with the main gradients environmental variables (Ph.r – pH of the topsoil porewater, Ec.r – EC of the topsoil porewater, alt – atlitude, n.days.5 – number of days with mean temperature ≥ 5° C, t.men.warm.q – mean temperature of the warmest quarter, max.warm.m – mean maximum temperature of the warmest month, prec.warm.q – precipitation of the warmest quarter, elements concentrations in porewater are represented by their standard abbreviations).

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CONCLUSIONS

The preliminary analyses presented above indicate that Finnmark's mires are highly diverse. Their differentiation is influenced by climatic, geological and local habitat factors. Considering only herbaceous plants and shrubs, 6 types of peatland vegetation have been identified, of which at least 3 (groups 1, 2 and 3) are clearly distinguishable from the others.

Groups 4 and 5, and partly also 6, are compositionally very similar, but at the same time they are distinguished by selected biotic and abiotic factors. I therefore assume that they will differentiate strongly when cryptogams are added to the analysis. It is worth mentioning that was also important from the point of view of biodiversity inventorying. For example I discovered two localities of *Meesia longiseta* – a moss, which has been recorded in Finnmark only once since the 19th century (Kyrkjeeide 2021). The significant increase in knowledge about the distribution of rare peatland plant species after one season of research indicates the need for further scientific work, including on the flora and ecology of mires in the Finnmark region.

ACKNOWLEDGEMENTS

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SESSION VI - INTO THE FUTURE: PREDICTING AND PLANNING

Implementation of the Nature Restoration Law more needed than ever: A case study from the most pristine (?) riverine wetlands in Poland

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INTRODUCTION

Recent decades have been critical and destructive for various freshwater wetlands in Poland and elsewhere. The situation seems set to get even worse in the coming decades. Pressures from agribusiness due to increasing demand for food and fodder, as well as water shortages due to increased evapotranspiration under climate change, are likely to significantly affect the hydrology of water-dependent ecosystems. The result is a progressive loss of wetlands located in diverse landscape and catchment contexts (Craft, 2016). This problem is particularly evident in the extensive peatland complex of the Biebrza Basin (NE Poland), which has been identified as a well-preserved, 'reference' wetland area.

METHODS

A soil survey was conducted in 2020-2022. Two hundred and ninety hand auger drill holes were completed, reaching down to the mineral substrate underlying organic deposits. For our study, we also used 353 soil borings by the Bureau for Forest Management and Geodesy in Bialystok in 2019-2021, our 84 soil cores from 2014 and 77 cores from 2009, and archival soil survey data covering the last three decades of the 20th century (1,112 soil samples).

Maps, as GIS feature classes, were generated using the QGIS 3.28.4-Firenze software (Free and Open Source Software (FOSS); Free Software Foundation, Inc., USA; www.qgis.org).

The material was statistically compiled using Statgraphics 18.

RESULTS and DISCUSSION

Soil survey conducted in the Biebrza Basin, protected as the Biebrza River National Park (59,729.63 ha), has shown that histosols are subject to unfavourable changes resulting from deteriorating hydrology (Banaszuk, 2023). The area of peat soils characterised by progressive subsidence and loss of organic matter amounted in 2022 to 22 323 ha, which is more than half of their area, while in 1999, the share of peat soils in the decession stage was 16 374 ha (36%). The disappearance of peat soils is particularly evident in peatlands in the middle Biebrza basin. These soils are deeply drained and formed of highly decomposed peats, which are highly susceptible to intensive mineralisation. There is a severe transformation of organic soils—histosols—into murshic histosols. Shallow histosols change to mineral soils like gleysols, umbric gleysols, and gleyic/stagnic phaeozems (WRB 2022).

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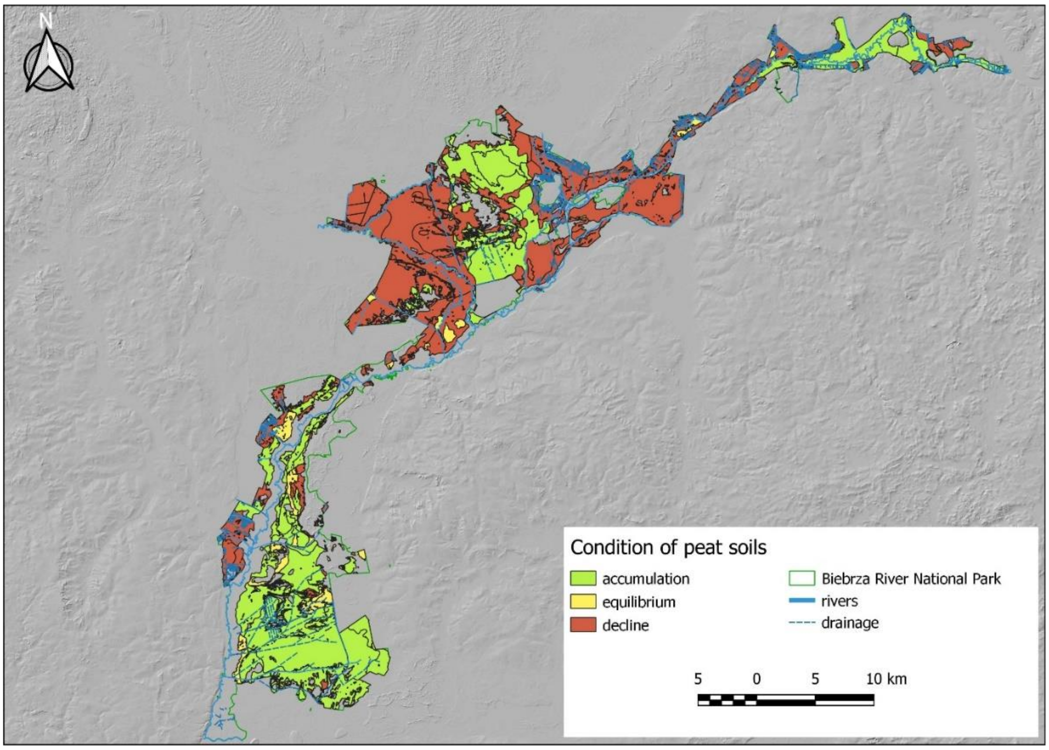

Fig. 1. Contemporary status of peat soils in the Biebrza River National Park - water-saturated organic soils with active accumulation process occupy smaller areas than with decay due to the drying process (Banaszuk, 2023).

Peat soils are estimated to be getting shallower at a 1.0-2.0 cm/year rate. Boosted decay of organic matter is associated with a release of CO_2 (minimum emission: 12.6-20.1 tons per hectare per year (Ghezelayagh et al., in press); maximum emission 25-46 tons per hectare per year (own estimates)). In places, a loss of more than 100 cm of peat has been recorded compared to the 1960s-70s (Fig. 2).

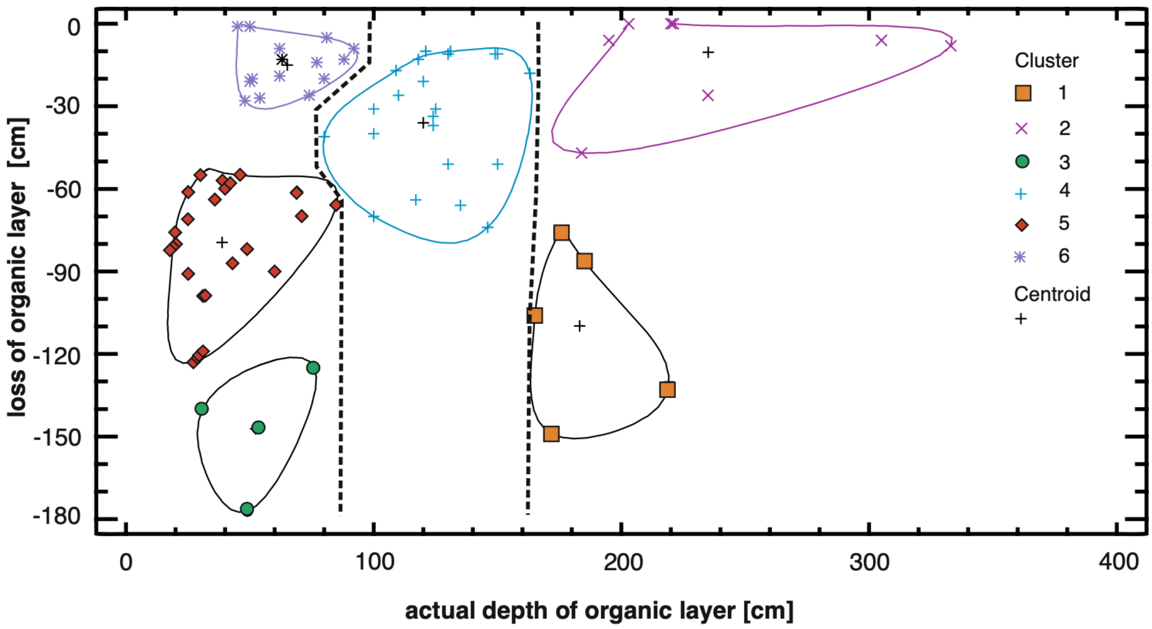

Fig. 2. The decline of histosols in relation to the organic sediment thickness sampled between 1970 and 1999.

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CONCLUSIONS

Changes in wetland and soil conditions in the Biebrza River Basin are occurring at an alarming pace, posing a severe threat to the quality of the environment, biodiversity, and climate. Large-scale restoration of wetlands is now more necessary than ever. A broad consensus is needed to develop a cooperative model for wetland conservation that satisfies not only conservationists but, above all, owners and stakeholders managing grasslands in wetlands.

ACKNOWLEDGEMENTS

Soil survey in Biebrza River National Park was supported by the Operational Program Infrastructure and Environment (POIS.02.04.00-00-0025/17) as part of the project "Preparation of a Management Plan for the Biebrza River National Park".

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SESSION VI - INTO THE FUTURE: PREDICTING AND PLANNING

Exploring the Impacts of Tree Encroachment and Mowing on Fungal Communities in Fens

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INTRODUCTION

Fens are the dominating peatland type in temperate Europe, and due to the high density of human population in this region, they face high anthropogenic pressure. Historically, many of them have been drained, primarily for agricultural purposes. The desiccation of peat results in its decomposition and emission of greenhouse gasses. Moreover, draining allows for tree encroachment, further transforming these ecosystems. Currently, mowing is used the most widely to prevent this process. Although successful in restoring plant communities (Hájková et al., 2022), its impact on the belowground microbial communities is unknown.

The dominant functional group of fungi in peatlands are saprotrophs (Juan-Ovejero et al., 2020). Typically, the physicochemical properties of the substrate have the most significant impact on the species composition of fungal communities in peatlands (Andersen et al., 2013). However, mycorrhizal fungi, also occurring in these habitats, are an exception, as their presence is correlated with the presence of plant partners. Ectomycorrhizal fungi (ECMF) form non-antagonistic interactions predominantly with trees and shrubs, while arbuscular mycorrhizal fungi (AMF) – with most herbaceous plants, and some trees and shrubs.

The objective of this study was to evaluate the impact of tree encroachment and mowing on fungal diversity and community composition in fens.

METHODS

Peat samples were collected at the depth of 10-20 cm, from open and wooded patches in 24 fens with varying management histories, distributed across northern Poland. The isolation of environmental DNA from peat samples was followed by the amplification of ITS2 rDNA fragments. Additionally, to detect AMF fungi, a nested PCR approach with *Glomeromycota*-specific primers was utilized to amplify 18S rDNA fragments. Subsequently, all resulting fragments were sequenced using the Illumina NovaSeq platform. Bioinformatic analysis was conducted using Qiime2 (Bolyen et al. 2019). 18S and ITS2 rDNA amplicons data were analysed separately. To classify OTUs into taxa we employed UNITE (Abarenkov et al. 2023ab) and MaarjAM (Öpik et al. 2010) databases for ITS2 and 18S rDNA fragments respectively. Then we assigned functional guilds to fungi using the FungalTraits database (Põlme et. al. 2020). All biodiversity comparisons and the statistical analysis were performed in the R programming language.

RESULTS and DISCUSSION

Based on ITS2 amplicons we detected 21119 OTUs of fungi belonging to 16 phyla and based on 18S rDNA fragments – 1345 OTUs of *Glomeromycota*. We found that in case of both AMF and fungi overall (Fig.1), the total diversity indices were affected neither by tree encroachment on natural fens, nor by mowing on disturbed fens. The overall dissimilarity of fungal communities between open and wooded patches was relatively low in disturbed fens, indicating the existence of a legacy effect, possibly linked to a degradation of peat. The dissimilarity in AMF community composition between the groups - open and wooded, as well as between fens with different management statuses was very low. The relative abundance of ECMF (mainly *Cortinariaceae* and *Inocybaceae*) was consistently higher in wooded patches (Fig.2), while for AMF there were no differences.

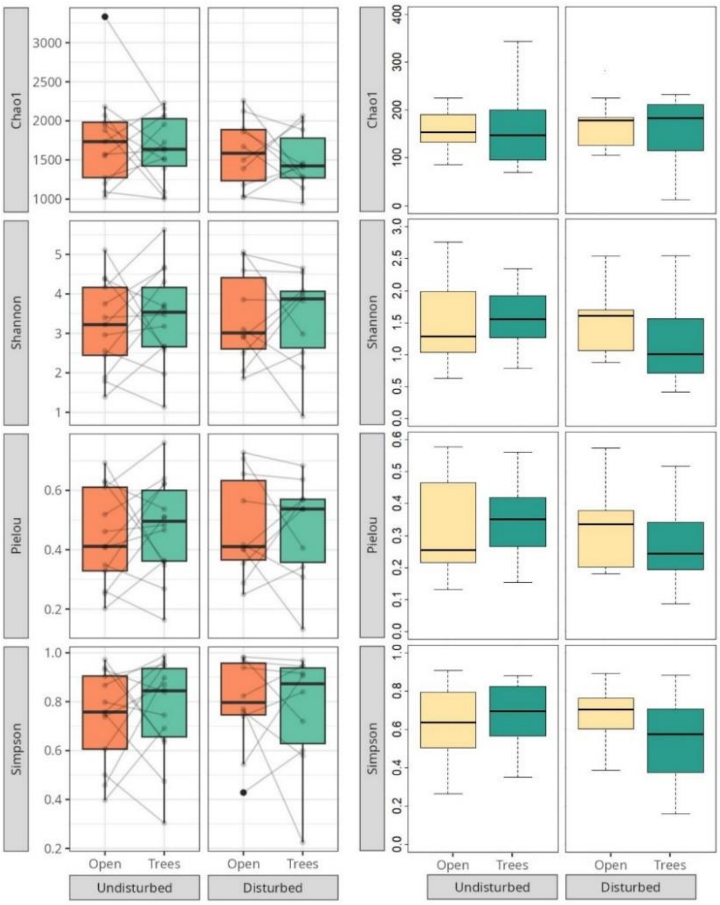

Fig. 1. The values of diversity indices of fungal communities (based on ITS2 rDNA) (left) and of AMF (based on 18S rDNA) (right) in samples divided into four variants – disturbed and undisturbed by mowing, open and with tree and shrub cover.

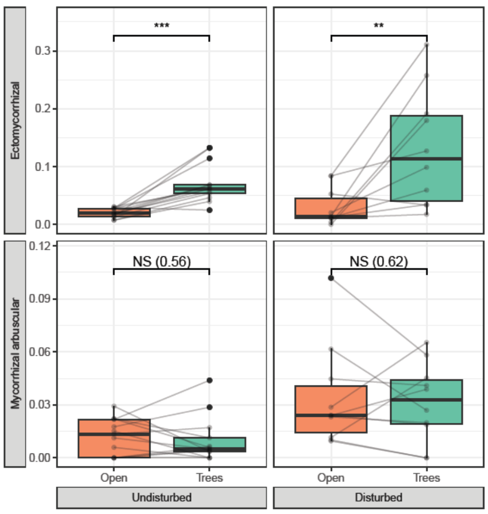

Fig. 2. The fraction of OTUs assigned to two of the functional groups in FungalTraits – ECMF and AMF, per all OTUs with assigned traits.

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CONCLUSIONS

Mowing has little effect on the overall fungal diversity and AMF appear to be relatively resilient towards this procedure. The main impact of mowing is the reduction in abundance of ectomycorrhizal fungi.

ACKNOWLEDGEMENTS

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SESSION VI - INTO THE FUTURE: PREDICTING AND PLANNING

How undisturbed are the percolation rich fens of the Rospuda Valley (NE-Poland) - a landscape ecological analysis

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INTRODUCTION

Knowledge about hydro-ecological processes and feedback-mechanisms in more or less pristine, peat-forming peatlands is essential for 1) determining the right restoration perspectives and strategies in degraded peatlands and 2) to determine the extent to which undisturbed mires and peatlands are under pressure from recent changes in regional hydrology and climate change.

The Rospuda Valley in NE-Poland is described as an "undisturbed" percolation rich fen (Jabłońska et al., 2011), which makes it very important for preservation of biodiversity. Nonetheless, the cover of (birch) forest has increased by about 70% after cessation of haying in the early 1970's, indicating water levels (at least periodically) below the surface (Wassen et al., 1992; Schippers et al., 2007). Additionally, *Sphagnum*-dominated small sedge vegetations are present in specific parts of the mire (Jabłońska et al., 2011, 2019), pointing to acidification due to changes in the throughflow mechanism (Van Loon et al., 2009). Because most forest grow on woodless peat types, we suggest that the development of most forest vegetations is a more recent development, which suggests that the percolation rich fens of the Rospuda Valley might, from a landscape ecological perspective, not be as pristine as has been assumed so far. In this research, we explore the hydro-ecological functioning of the Rospuda mire at landscape scale and try to understand how hydrological conditions have changed over time and how this affected vegetation patterns.

METHODS

To get an understanding of the hydro-ecological functioning of the percolation rich-fen of the Rospuda, we collected data of peat types, water chemistry, vegetation composition, water level fluctuations between April and August 2023 and flow direction on three transects. All transects cover the entire gradient from mineral edge (east side) up to the river (west side). We conducted about 40 peat corings up to 6 meters in all vegetation types and collected water samples from the uppermost peat layer (10-15 cm - surface level) as well as from some deeper peat layers (up to 100 cm - surface level) in April, June and August 2023. At all locations we also conducted EC-measurements up to 3 meter depth to get an understanding of the stratigraphy in water quality. All data was processed into hydro-ecological cross sections. We analyzed water chemistry with PCA-analysis and, classified the data in three significantly different water types based on a hierarchical clustering analysis.

RESULTS and DISCUSSION

Although the peat was mainly formed by brown-moss peat and small-sedge peat, every cross-section shows a different spatial pattern in peat stratification. Spatial differences in peat thickness, peat stratification and degree of humification indicate different vegetation types and hydrological conditions during peat formation throughout the mire (Fig. 1). There are also some specific areas with a thin layer of sphagnum – small sedge peat (<20 cm), which was developed on the recent root layer.

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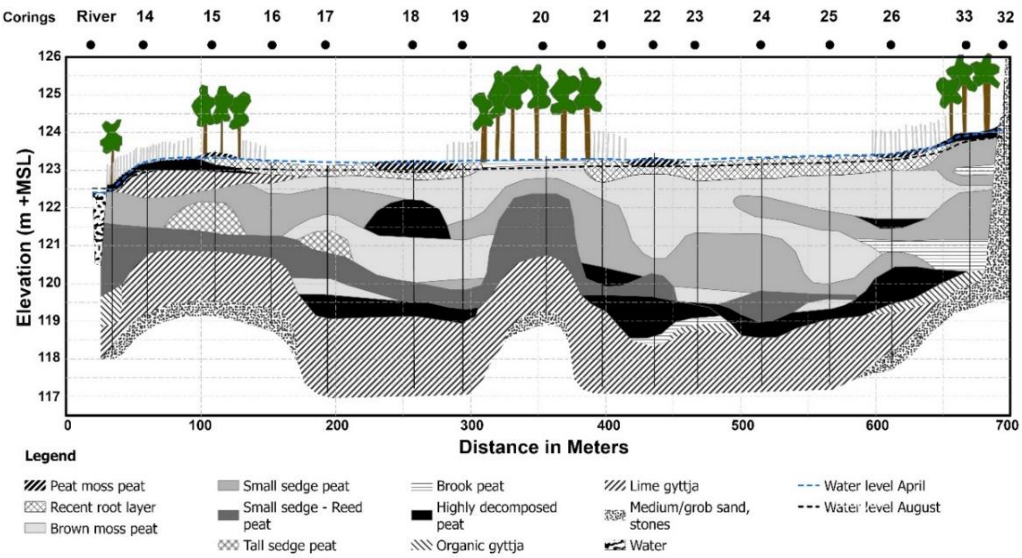

Fig.1. Stratigraphy of the norther transect in the Rospuda Valley.

Water levels stayed on average within 10 cm (±1.2cm) from the mires surface in brown moss and small sedge vegetations. In forest vegetations summer water levels (August 2023) dropped more than 21 cm (±2,4cm) below the surface level. This confirms the conclusion that water level dynamics explain most differences in vegetation types (Jabłońska et al. 2011). The Rospuda River has a draining effect, as it has a 30-70 cm lower water level compared to the mire (Figure 1). Daily measurements of water level fluctuations in the mire show a water level decrease by about 15 cm between April and August, whereby the rivers level increased by about 10 cm. High and stable groundwater tables close to the river in the northern parts of the mire, can only be explained by a constant inflow of groundwater. In the southern part of the mire (with large areas of forest), water levels in August were equal to the water level of the river, indicating that the influence of inflowing groundwater is considerably less dominant and depends much more on the rivers water level.

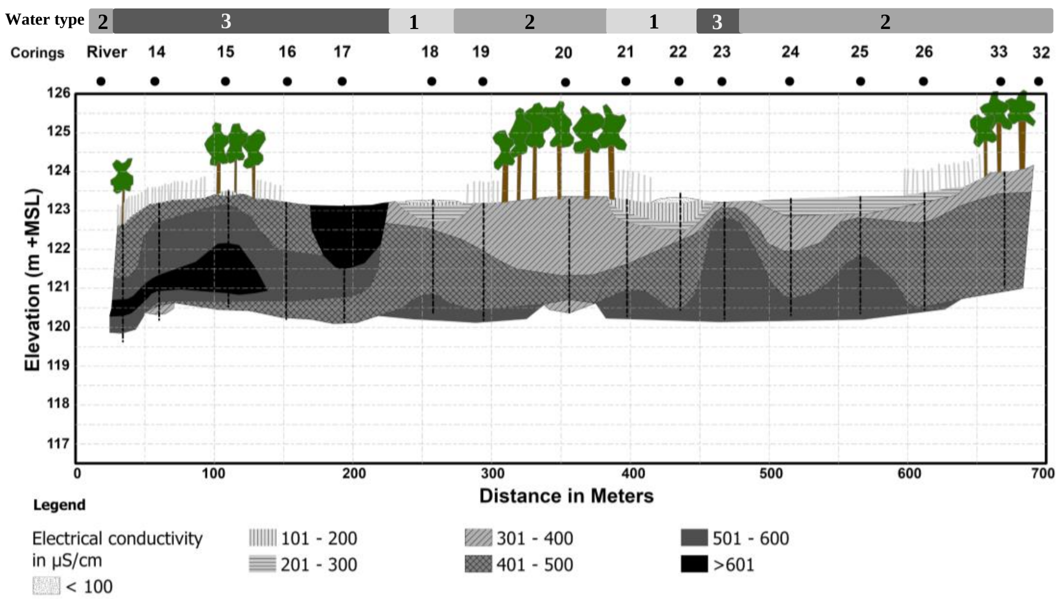

Fig. 2. EC-measurements in the peat up to 3 meter deep and distribution of different water types as found in the hierarchical cluster analysis 1) base-poor type, 2) base-rich type and 3) alkaline type.

Water samples were classified into three significantly different water types: 1) relatively base-poor, 2) base-rich and 3) highly alkaline groundwater. EC-measurements in the peat show the spatial distribution of the water types (Fig. 2). Stagnation of base-poor water implies that these areas do not receive enough base-rich groundwater through the uppermost peat layer to maintain a rich fen vegetation. Base-rich groundwater from the mires edge (west site) is not redistributed over the entire mire surface anymore. This means that 1) the predominant flow direction of groundwater is directed southeast, i.e. parallel to the river (confirmed by tracer dye), and 2) highly alkaline groundwater in the west has to discharge from below the mire and also flows southward parallel to the river.

CONCLUSIONS

Our landscape ecological analyses show that forest vegetations are characterized by a summer water level more than 21 cm below the surface. Conditions in the past were much wetter, shown by the more or less woodless peat types under the forests. The water level of the Rospuda River was 30-70 cm below the mire surface, draining the mire year-round.

As a result of a highly decomposed uppermost peat layer in forested areas, flow patterns of the superficial groundwater changed and base-rich groundwater no longer reaches all parts of the mires surface. Rainwater lenses were formed and sphagnum dominated vegetations occurred in these areas. We conclude that base-rich groundwater discharges in specific areas in the northern part of the mire as well as along the eastern margin of the mire, from where it is transported southeastwards through the uppermost peat layer, which corresponds with the distribution of base-rich fen vegetations (Jabłońska et al., 2011).

Digital elevation models shows signs of backwards erosion of the river, leading to the hypothesis that water level dynamics of the river have changed, most likely after building the Augustow Channels in 1830, which might have initiated backwards erosion and a water level below the mires surface. High and stable groundwater levels in the percolation rich fen can nowadays only be maintained if there is a sufficient supply of discharging groundwater evenly distributed over the year. A reduction in hydraulic head of groundwater could lead into much lower water levels in the entire mire, which will be destructive to the ecosystem. Although the Rospuda percolation rich fen is “undisturbed” in a sense of direct human deterioration, the percolation mire as a functional ecosystem is affected by the low water levels of the Rospuda River relative to the mires surface.

ACKNOWLEDGEMENTS

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SESSION VI - INTO THE FUTURE: PREDICTING AND PLANNING

Stability is the key – the peat formation potential of fens increases with decreasing water level fluctuations

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INTRODUCTION

Mires, ecosystems with stable water levels slightly below the surface, create anaerobic conditions that slow organic matter decomposition, allowing peat accumulation. Fens, a type of mire fed by groundwater rich in calcium and magnesium ions, are characterized by zonation of plant communities from the valley edge to the river (Wassen et al., 2002; Jabłońska et al., 2011). Sedge-moss fens, dominated by brown mosses, develop in hydrologically stable, nutrient-poor areas, supporting many rare plant species. In contrast, fluctuating water levels increase nutrient availability, promoting the growth of tall wetland plants that outcompete brown mosses (Kotowski et al., 2006). The peat formation potential in fens depends on biomass type and abiotic factors, particularly groundwater stability.

Despite the recognized role of peatlands in carbon sequestration, our understanding of peat formation mechanisms is limited to *Sphagnum*-dominated bogs, while fens, which cover over half of peatland areas (Tanneberger et al., 2021), remain less studied. Fens exhibit ecological diversity with plant communities varying along hydrological and nutrient gradients. These gradients influence peat formation by controlling biomass production and decomposition, both directly through abiotic factors and indirectly through species composition changes. This study aims to compare the first-year biomass surplus (peat-forming potential) across ecohydrological gradients in rich fens of the Biebrza and Rospuda valleys in NE Poland.

METHODS

We conducted field research along seven transects in the Biebrza and Rospuda valleys, covering hydrological and nutrient gradients from oligotrophic sedge-moss to meso- and eutrophic tall sedge communities. We measured production and decomposition of above and belowground biomass of vascular plants and dominant brown moss species occurring in fens. We compered two methods to measure brown moss biomass growth: oil paint marking and the plug method. Decomposition rates were measured using the 'litter bag' method. Additionally, we conducted a greenhouse experiment, which tested moss growth in varying nitrogen availability.

RESULTS and DISCUSSION

Peat accumulation was highest at stable groundwater sites and decreased with water level fluctuations due to rapid brown moss growth in stable, oligotrophic conditions, while decomposition rates remained constant. The findings highlight the importance of brown mosses in fens, similar to the role of *Sphagnum* in bogs. Competitive interactions with vascular plants, influenced by hydrological and nutrient gradients, play a key role in peat formation. Experimental results showed brown mosses have a wider fundamental niche than their realized niche, limited by competition for light. The most reliable method for measuring moss growth was the plug method, as it allows measuring growth of the entire plant, including lateral stems, which is crucial for accurate biomass production estimates.

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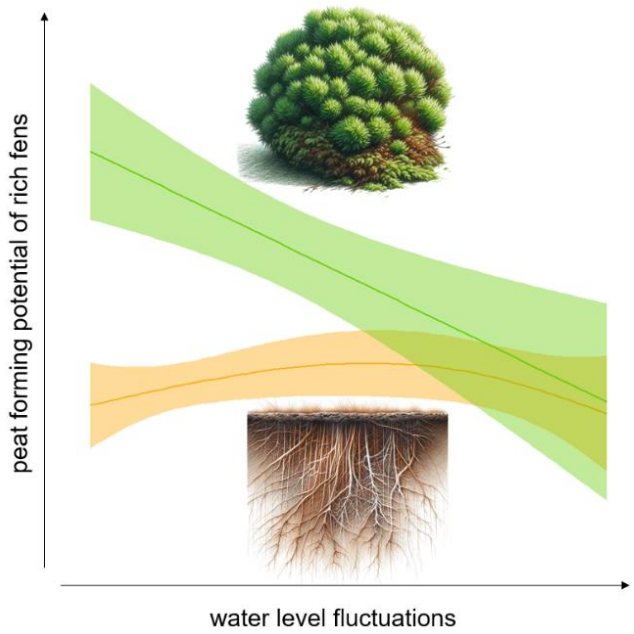
CONCLUSIONS

This study confirms that stable groundwater levels enhance peat accumulation, demonstrating the significant role of brown mosses in peat formation in temperate fens. Competitive dynamics, rather than nutrient availability, limit brown mosses in natural conditions. Protecting near natural sedge-moss fens, particularly through maintaining stable water levels, is crucial for preserving their peat-forming capabilities.



Ryc. 1. Conceptual summary of research findings. The orange line shows the annual surplus of belowground biomass of vascular plants as a function of water level fluctuations. The green line adds the contribution that brown mosses make to the annual biomass surplus. The root and moss drawings were generated by AI.

ACKNOWLEDGEMENTS

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SESSION VI - INTO THE FUTURE: PREDICTING AND PLANNING

Setting the global agenda for wetlands: The past and future of strategic planning for the Convention on Wetlands

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INTRODUCTION

The Convention on Wetlands (the 'Ramsar Convention') is the intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of all types of wetlands. The work of the Convention is guided by the Ramsar Strategic Plan. To date, the Convention has worked to four Strategic Plans. The current (Fourth) Strategic Plan has been implemented since 2016 and is due to finish in 2024.

Depressingly, over the period of the Fourth Strategic Plan the deterioration of wetlands remains widespread, with wetland losses still occurring at alarming rates, and more than 50 years after the Convention on Wetlands was adopted, its mission is more urgent than ever. To deliver on its mission, the Convention is in the process of developing the Fifth Strategic Plan that will set the global agenda for wetland wise use from 2025 through to 2030.

The Society of Wetland Scientists has a memorandum of cooperation with the Convention and, through the Society's Ramsar Section, regularly contributes to Convention processes.

This presentation will describe the historical strategic planning process that the Convention on Wetlands has undertaken and will explain the process behind developing the specific goals, objectives and targets for the Convention's Fifth Strategic Plan.

METHODS

The development of the 5th Strategic Plan is on-going. To date the development has utilized three main approaches to establishing a robust evidence-base upon which to set the future direction of the Convention, namely: (1) consultation and engagement with a variety of stakeholder; (2) a detailed literature and information review; and (3) analysis of Convention reporting and processes. The main messages and issues derived from these three approaches will be described.

DISCUSSION

The draft goals and targets of the 5th Strategic Plan will be presented. This will provide the conference attendees with an opportunity to comment and provide input in shaping the global wetland conservation agenda.

ACKNOWLEDGEMENTS

The work presented has been supported by considerable input from many stakeholders, partners and Contracting Parties to the Convention on Wetlands. A small consultancy team has steered the development process, without whom this presentation would not have been possible. These individuals a rightly acknowledged: Christine Prietto, Luisa Ricaurte, Nick Davidson, Matt Simpson, Priyanie Amerasinghe, Rebecca Woodward and Sana Mezoughi.

SESSION VI - INTO THE FUTURE: PREDICTING AND PLANNING

Tidal Forest Productivity and Biodiversity: A Southeastern U.S. Perspective

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INTRODUCTION

Tidal freshwater forests occupy only a small proportion of coastal wetland habitat yet provide a number of ecosystems services including wood and honey production, tree and groundcover biodiversity, migratory songbird habitat, water quality improvement and carbon (C) sequestration. We characterized stand density, basal area and diversity and groundcover diversity in a tidal forest of the Altamaha River, Georgia, USA. We further measured aboveground productivity (litterfall, stem wood increment) over an 8 year period (2015-2023) and characterized food webs and feeding habits of a non-game migratory songbird (Northern Parula Warbler), a species of concern.

METHODS

We measured aboveground growth using litterfall and stem wood increment in two 0.1 ha plots (Stahl et al., 2018). Density and basal area of each tree species was measured in both plots. Litterfall was measured monthly using eight 0.25 m^2 litter traps. Stem wood increment was measured on a subset of 40 trees using dendrometer bands. Groundcover was measured in four 5m radius plots. Nongame migratory songbirds were sampled using mist nets and recorded calls (Brittain et al., 2010). The sex and age of birds that flew into the net were determined. A feather was collected from each bird and analyzed for stable isotopes of C (^{13}C) and N (^{15}N) (Brittain et al., 2012).

RESULTS and DISCUSSION

The forest was dominated by Tupelo gum (*Nyssa aquatica*, 50%), Sweet gum (*Liquidambar styraciflua*, 13%) and Black gum (*N. sylvatica*, 11%). Bald cypress (*Taxodium distichum),* the largest trees in the stand, accounted for only 3% of density but 13% of basal area. Aboveground productivity (900-1100 g/m2/yr) was remarkably similar across 9 years of sampling with litterfall accounting for 56-68% of the total and wood increment the remainder. Groundcover was dominated by dwarf Palmetto (*Sabal minor*, 17%) and grasses, sedges, & herbaceous wildflowers that varied throughout the year.

The Northern Parula Warbler (*Selophaga americana*) relies on tidal forest, especially the epiphyte, Spanish Moss (*Tillandsia usneoides*) for nesting. Stable isotope (^{13}C, ^{15}N) analysis of feathers revealed that the species feeds primarily on invertebrates in the C3-dominated forest with detritivores accounting for 45% of its food.

CONCLUSIONS

As is the case with most coastal regions worldwide, sea level is rising along the Georgia coast and the rate of rise is accelerating. Model simulations of sea level rise of the Georgia and southeastern U.S. coast suggest that, by 2100, 24% of tidal forest will be lost with a comparable reduction in the population of Northern Parula Warblers (Brittain and Craft 2012). In addition to declines in migratory songbird habitat, it is expected that the loss of tidal forest will lead to declines in biodiversity and other ecosystems services.

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Predicted effects of climate change on native and alien fishes in a large floodplain river (Middle Vistula River, Poland)

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INTRODUCTION

The climate change we are witnessing presents organisms with entirely new and previously unknown challenges. Freshwater ecosystems appear to be particularly vulnerable to negative changes, as the quantity and quality of water depends not only on changes in temperature alone, but also on the amount of precipitation – itself dependent on climate change (Capon et al. 2021). Globally, rivers are warming at an average rate of 0.16°C per decade, and even up to 1°C degree per decade in some regions (Liu et al. 2020). It was recently found that over the last 40 years the Vistula River has warmed at a rate of 0.1–0.4°C per decade (Cebula et al. 2021, Ptak et al. 2022). This raises concerns about the functioning of fish populations, which, as ectotherms, are more vulnerable to temperature changes.

Fish are ectotherms and warming of a waterbody affects them in a number of ways through changes in metabolism, reproductive physiology and behaviour. In addition, each life stage of a given species has different thermal preferences and tolerances. In general, fish mature more quickly in warmer waters and spawning tends to occur earlier in the season. The extended growing season allows juveniles to feed for a longer period of time and reach a larger body size before the first winter. On the other hand, higher temperatures can lead to oxygen depletion, which can slow down fish growth or even cause them to emigrate from a particular area. If emigration is not an option, prolonged periods of heat stress may lead to local extinctions of more vulnerable species (Pörtner and Farrell 2008, Dahlke et al. 2020).

The aim of the present study was to predict changes in the thermal regime of the Vistula River in the short (2050) and long term (2100) and under two climate change scenarios (RCP 4.5 and 8.5) and their possible impact on the functioning of native and non-native fish species in the Middle Vistula. As a floodplain river, the Middle Vistula consists of a complex of river channels and adjacent water bodies with varying connectivity to the main channel. Water temperature in the main channel depends largely on air temperature, hydrological processes and floodplain heating. Water temperature is very difficult to model in such a complex system. We therefore opted for a simpler, less data-intensive solution, i.e. a stochastic approach in which the water temperature at a given gauging station was related to the air temperature at a nearby weather station.

METHODS

The CHASE-PL (CPLCP-GDPT5) dataset (Mezghani et al., 2017) was used as the basis for the modelling, consisting of gridded 5 × 5 km data of historical simulations and forecasts of daily minimum and maximum temperatures and precipitation. The set comprises a total of 9 EURO-CORDEX regional climate models scaled down to 5 km resolution and subjected to outlier correction using a quantile mapping approach. The historical simulations covered the period from 1971 to 2020. The projections covered two periods: for 2021–2050 and 2071–2100. The projected data were based on two emission scenarios, RCP 4.5 and RCP 8.5 (van Vuuren et al. 2011). Forecasts based on the CNRM-CM5.1 model (Voldoire et al., 2013) were used in this study due to its good compatibility with hydrological models (Usman et al. 2021).

The predicted air temperature values were translated into water temperature using a simple linear regression model with a 3-day lag. Such a stochastic approach was proved to be very useful for data-limited situations (Rosencranz et al., 2021). The model considered data from three pairs of river gauges and meteorological stations collected between 1981 and 2021 (data obtained from publicly available database of IMGW).

Critical values of water temperature for particular fish species were based on extensive literature review (mainly: Brylińska 2000, Souchon and Tissot 2012, Golovanov 2013 and literature cited therein). The acceleration of the breeding season was predicted using the Pauly and Liang (2022) sinusoidal model. Thermal safety margins (TSM) were assessed according to Dalhke et al. (2020).

RESULTS and DISCUSSION

Under the RCP 4.5 scenario, an initial decrease (*sic*!) in mean annual water temperatures is projected: from 0.3°C in Sandomierz to almost 0.7°C in Wyszogród (nevertheless, this means an increase relative to the 1980s). After this initial “cooling”, by the end of the century, an increase in mean annual temperatures of 0.7–1.0°C (relative to the 2001–2010 period) is projected. Under the RCP 8.5 scenario, the initial drop in temperatures is smaller (by 0.03–0.3°C relative to the 2001–2010; it corresponds to an 1.1°C increase relative to the 1980s), and the subsequent increase by 2100 is much larger: 1.9–2.2°C *vs*. 2001–2010 and 2.0–3.4°C *vs*. 1981–1990. Apart from the most extreme option (RCP 8.5 in the long term perspective), none of the models predicts an increase in average monthly water temperatures during the summer months. The largest changes will occur in the winter-spring months and, slightly smaller, in the autumn months. Under the RCP 8.5 and long-range forecast scenario, average monthly temperatures could increase by 3.6–4.9°C in the winter-spring period. Under the RCP 4.5 and long-range scenario, the largest temperature increase is predicted in March and April (3.7–3.8°C), with a slightly lower increase in the winter months (1.6–2.6°C).

For two of the three gauging stations, an increase in the number of days with water temperatures exceeding 25°C is predicted. This value is taken as the threshold of “stressful temperature” for a significant part of the Vistula ichthyofauna. In the short-term forecasting horizon – regardless of the scenario – the number of days with temperatures >25°C will double. In the period 2091–2100 and the RCP 4.5 scenario, it could increase by up to three or four times comparing to the historical data. Under the RCP 8.5 scenario and in the long term, the number of “stress” days will reach half a month.

The total sum of heat, the so-called number of degree-days (°D) follows similar pattern. In the decade 2001–2010, the average number of degree-days in the Middle Vistula ranged from 3700 to 4000°D. In the short forecasting horizon, these values will increase by about 100–150°D. By the end of the century, it will increase to around 4400–4500°D (RCP 4.5) or even 4800–4900°D (RCP 8.5). This represents an increase from 9–19% up to 20–30% (depending on the scenario) over the average of the last decade. The number of degree days directly influences the rate of maturation of gonads and is largely responsible for the reproductive phenology of individual species. As a result, the attainment of sexual maturity will be accelerated and the spawning season will start earlier by 1.0–2.9 and 8.6–15.4 days in short and long terms, respectively.

Analysis of TSM (Dahlke et al., 2020) suggests that the predicted temperature increase in the Middle Vistula will not pose a threat to adults of most species. However, for some (e.g. burbot *Lota lota*, chub *Squalius cephalus*, asp *Leuciscus aspius*, or spirlin *Alburnoides bipunctatus*), the predicted TSM values are worryingly low, especially for spawners and embryos. It will be probably compensated for by the mentioned changes in reproductive phenology (accelerated spawning). On the other hand, the predicted changes in the number of degree-days and higher spring temperatures pose a potential threat of establishment of non-native species that have so far not successfully reproduced in the Middle Vistula. Of particular concern are the Asian carps (*Hypophthalmichthys* spp.) and grass carp (*Ctenopharyngodon idella*).

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CONCLUSIONS

There has been an undeniable increase in the Vistula River water temperature in recent decades. According to our predictions, this increase will continue in the following years, causing significant changes in the thermal regime of this river and resulting in changes in the functioning of fish populations (e.g. acceleration of reproduction). Although the majority of species inhabiting the Middle Vistula are eurythermal, there are some among them that may be threatened by the coming changes. Additionally, the warming of the Middle Vistula may create conditions conducive to invasion by non-native species. A separate issue is the warming of waterbodies in the floodplain. This hitherto neglected topic should become the subject of monitoring in the near future.

ACKNOWLEDGEMENTS

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High resolution assessment of the state of river hydromorphology in Poland: legacy of the past, challenges for now and for the future

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INTRODUCTION

For centuries, water management in Poland was focused on managing excess water. As a result, starting from the 18th century in western Poland, rivers were intensively regulated: their beds were straightened, river valleys were drained and limited by flood embankments. Intensive, large-scale transformations of river catchments and drainage of peat bogs in eastern Poland occurred after World War II. As a consequence of this approach to water management, Poland is covered with a network of drainage ditches, the total length of which is approximately 320,000 linear kilometers. In most cases, ditches have only a drainage function because they are devoid of water damming devices. In the last century, Poland also went through a period of very intense and uncontrolled pollution of rivers with municipal and industrial sewage. Already 20 years of Poland's membership in the European Union have not been properly used to improve the condition of river ecosystems and other surface waters, as well as peat bogs and other wetlands in river valleys. Progress has been made mainly in reducing industrial and municipal pollution. However, traditional approaches based on gray infrastructure continued to dominate river management. The riverbeds were still being straightened. In this way, at least 1,000 linear km of watercourses were degraded in years 2007-2013. So-called maintenance works were carried out on a massive scale, consisting of deepening the bottoms of small rivers and streams (dredging) and removing natural riparian vegetation. These works were aimed at accelerating the outflow of water from small catchments. Such works covered at least 40,000 linear km of watercourses, which had an impact on the wetlands associated with the rivers. The problem of water retention in old drainage ditch systems has not been solved. On the contrary, new ditches without water damming devices were added. Although rivers and peat bogs have also been restored over the last two decades in Poland, the deterioration of river hydromorphology has been at least an order of magnitude faster than the restoration of rivers and wetlands. As a result, more than 90% of Water Bodies in Poland have not yet achieved the good status required by the Water Framework Directive. Analyzes carried out as part of the National Surface Water Restoration Program developed in 2019 showed that 83% of main rivers, the condition of which is monitored as part of the WFD implementation, require restoration to achieve good ecological status.

In the face of climate change and repeated episodes of drought in Poland, it is necessary to change the approach to river management. To achieve a significant improvement in the condition of the river ecosystem and to better manage the risk of drought and floods, it is not enough to take actions only on main watercourses belonging to riverine water bodies, which constitute approx. 33% of the length of all rivers and streams and about 50% of the water surface of watercourses in Poland. A comprehensive look at catchments is necessary, covering the entire river continuum. In times of climate change, the issue of shading riverbeds is becoming increasingly important, as shade on smaller rivers has a decisive impact on the structure of the river ecosystem and may be necessary to ensure survival conditions for cold-water fish species. As a support for activities undertaken to improve the management of Polish rivers, we have attempted to carry out a detailed valorization of the hydromorphology of the entire river continuum in Poland, covering approximately 200,000 linear km of watercourses (approx. 150,000 km of permanent rivers and streams and approximately 50,000 km of small spring streams and periodic watercourses) on an area of approximately 312,000 km^2 of land. This assessment of the hydromorphological condition is carried out as part of the independent Initiative "The Most Valuable Rivers and Streams in Poland", the main goal of which is to identify the best-preserved sections of watercourses to ensure their proper conservation. This is a project carried out since 2015 by the WWF Poland Foundation and the University of Life Sciences in Poznań, with pro bono support from MGGP Aero, deepsense.ai and the Warsaw University of Technology.

METHODS

All Polish rivers and streams were divided into 2 km long sections in the case of smaller rivers, and 4 and 8 km long sections in the case of medium and large rivers. Each of them is assessed in accordance with the Polish national standard assessment method based on the GIS component of the Hydromorphological Index for Rivers (HIR). The assessment is based on the remote sensing data and spatial databases. The HIR method is based on the GIS Hydromorphological Diversity Score (GIS-HDS) containing 7 assessment parameters and the GIS Hydromorphological Modification Score (GIS-HMS) including 6 parameters. Our analyzes were conducted with use of publicly available databases, mainly the Topographic Objects Database and the Map of Hydrographic Division of Poland 1:10,000.

One of the GIS-HDS parameters is based on the presence of oxbow lakes in the river valley. The identification of oxbow lakes that we used was based on an AI image classification model developed by deepsense.ai, which analyzed about 200,000 small water bodies located in river valleys. Based on this algorithm, the probability with which a given water body presented in the form of a vector image could be classified into each of three categories was given. These categories consisted of an oxbow lake, an artificial water body and natural water body other than an oxbow lake or one whose origin is difficult to determine. The AI-based water body classifier was evaluated through manual verification on a randomly selected sample of 1,000 water bodies. The verification included comparing the classification made by the model with the classification made by a human who had the ability to compare the vector image of a given water body with satellite images, a three-dimensional terrain model, etc.

Due to the need to better address the problem of drought and the threat to the further occurrence of cold-water salmonids in Polish rivers, we have extended the standard of the HIR method with additional parameters. These were: of the occurrence of ditches draining river valleys and entire catchments, the impact of mining, lost and deteriorated river habitat, and shading of riverbeds.

The index enabling the assessment of shading of 2-8 km sections of riverbeds developed by MGGP Aero was based on a LiDAR data and proprietary algorithm enabling measurement of the area of the riverbed shaded by trees and tall shrubs from 1 to 5 times, in five hours in the proximity of the astronomical noon on the longest day of the year.

RESULTS and DISCUSSION

The preliminary results of our detailed analysis of the entire river continuum in Poland are similar to our earlier analysis of the hydromorphological state of the main rivers (3016 riverine water bodies). Sections of rivers 2-8 km long with a high degree of naturalness are very rare. Most of the sections of rivers and streams have been transformed by humans to such an extent that at least partial restoration will be necessary. The analysis of individual parameters of the degree of naturalness and anthropogenic modifications of riverbeds and valleys shows a repeatable pattern: most heavily transformed and artificial watercourses occur in the lowland part of Poland, especially in its central and eastern parts. Streams in the upland and mountain areas in the south and north of the country are relatively better preserved (Fig. 1).

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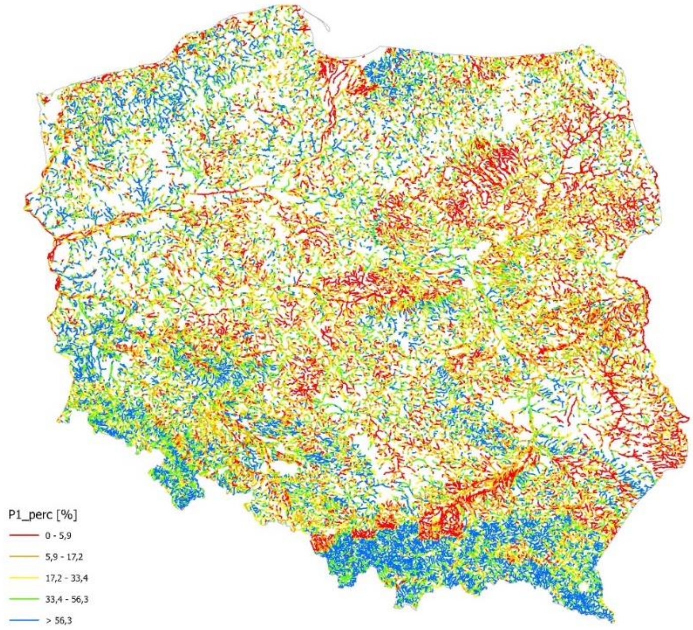

Fig. 1. Preliminary assessment of the woodland riparian zone in Poland – example of parameters of the state of the river and stream hydromorphology (N = 72 851 sections of permanent watercourses 2-8 km long). Analysis carried out by MGGP Aero based on a LiDAR data. Class 1 marked with blue – woodland riparian zone well developed

The analysis of small water bodies in river valleys showed that in Poland there are about 19,000 oxbow lakes and about 75,000 small water bodies of difficult to determine origin, which may play a similar ecological role as oxbow lakes.

The riverbed shading index shows a similar pattern to the overall condition of the riverbeds. Shading is best developed in mountainous and upland areas. A characteristic feature of many rivers in eastern Poland with peat valleys is the low shading of the riverbed with woody vegetation despite a well-preserved, close to natural riverbed route.

An analysis covering the entire river continuum in Poland confirms the urgent need to undertake large-scale restoration activities. At the same time, we hope that the results of our work will contribute to the designation and ensuring effective protection of the best-preserved parts of rivers and streams and their valleys in Poland, which should be free from any unjustified human interference. Our assessment of the state of hydromorphology may also contribute to the optimization of planning the restoration of transformed watercourses: identifying river stretches where a significant improvement in the state of the river ecosystem can be achieved with low financial outlays. Our analyzes can also contribute to improving the protection of oxbow lakes against destruction caused by human activity and against disappearance resulting from climate change and the general overdrying of Polish river valleys. We hope that our results of measuring the shading of riverbeds will become a motivation and a starting point for developing Polish national priorities for the restoration of riverine vegetation.

The results of our analyzes conducted using GIS tools and other modern technologies indicate also that with such a scale of work (ca. 100,000 analyzed sections of rivers and streams), it is impossible to avoid errors. Therefore, our results should be considered as a preliminary assessment that requires manual verification, for example checking selected quantitative results through human-conducted analysis of satellite images and other available data, such as a LiDAR. It will also be necessary to conduct field verification of selected river stretches and streams within the entire river continuum, especially those sections that should be protected as the most valuable, best-preserved fragments of riverbeds, river valleys and associated wetlands, which are presumably local centers of biodiversity related to river ecosystem.

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We would like to thank the three-person team from deepsense.ai, the two-person team from MGGP Aero and the seven-person HYMO Team from WWF and the University of Life Sciences in Poznań for your enormous contribution to this huge undertaking, which is the high-resolution assessment of the hydromorphology of the entire river continuum in a country the size of Poland. Without your great commitment, creativity, determination and patience, this task would not be possible.

Restoration of rivers in Poland. Experiences and challenges

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INTRODUCTION

Poland, like many European countries, faces a great challenge in improving the condition of surface waters (Leś, 2023). One of the main pressures affecting their poor or unsatisfactory condition is hydromorphological transformations.

The government document on the restoration of surface waters (PGW WP, 2020) indicates directions for restoration, based on national and foreign good practices and guidelines. The indications from this document were partly implemented in the existing river basin management plans. They indicated a total of more than 500 rivers (surface water bodies) in which restoration measures should be properly planned and implemented by the end of 2027 to achieve environmental objectives (Biedroń and Brzóska, 2024).

Noting that the scale of restoration needs in Poland concerns more than 90% (PGW WP 2020) of rivers, and in river basin management plans measures are planned for 16% of rivers with such diagnosed needs (Biedroń and Brzóska, 2024) - their timely implementation requires instrumental support and the openness and willingness of a number of stakeholders. This applies not only to the water administration, but especially to local governments and riverine communities, who should be considered as key target groups for such intentions (PGW WP 2020).

Faced with the challenge of restoring lost wetland ecosystem services as part of the European Green Deal and the proposed Nature Restoration Law 2023, the Institute of Meteorology and Water Management - National Research Institute is undertaking an expert study to inventory restoration projects carried out so far in Poland, covering rivers and their valleys, and to examine the effectiveness of the restoration measures implemented.

METHODS

The research focuses on building a spatial database in a GIS environment of sites where restoration activities have been carried out on a national scale. Information feeding the database comes from official documentation and other reliable sources. To collect the data, among other things, a dedicated Google map service has been launched, which has been made available to specific individuals who have field knowledge and can spatially mark restoration sites. The qualification of the types of restoration activities will refer to the Catalogue of Activities defined in the government document (PGW WP, 2020).

River restoration projects undertaken will be presented on a timeline. This information will be set against the current plans for river restoration in the coming years and their target needs, resulting from the National programme for surface waters' restoration (PGW WP 2020).

Ultimately, an attempt will be made to develop a set of indicators that will reflect the effectiveness of the implemented measures in terms of: improvement of natural retention, increase of biodiversity or improvement of the ecological status of surface waters. An indication of the effectiveness of the restoration measures implemented can reinforce the implementation of national and international policies related to the need to upscale the restoration of rivers and other wetlands.

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The scope of information to be collected in the database will be discussed and agreed with an expert team representing the scientific and research community, NGOs and water administration.

RESULTS AND DISCUSSION

The study has been scheduled for implementation at the end of the first quarter of 2025. Working, partial results of the study will be presented at the conference. The discussion that will emerge during the conference may have a direct impact on the further implementation of the study.

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Land requirements for floodplain development and restoration in Europe

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How can the 20 % priority area target for nature conservation and 25,000 km of free-flowing rivers be achieved?

INTRODUCTION

In Europe, between 70 and 90 per cent of floodplains have disappeared or are no longer connected to the river system (Tockner and Standford 2002, Verhoeven 2004, EEA 2016). This results in an enormous need for restoration. Potential restoration areas can be found in the former floodplain, which in turn is used by a variety of human activities, such as urbanisation, transport infrastructure and, above all, agriculture, as spatial analyses of the morphological floodplain for Europe show (EEA 2020, Koenzen et al., 2021). The remaining active floodplains are important hotspots of biodiversity and at the same time provide important ecosystem services, for example by acting as a sponge in the event of floods and droughts, as well as having a major purification function for rivers and streams. As carbon stocks, they can also reduce greenhouse gas emissions (Scholz et al., 2012).

The recently passed European Nature Restoration Act will also pose major challenges for river and floodplain management in the coming years (Hering et al., 2023). Important questions here are how 25,000 kilometres of free-flowing rivers and, above all, the 20% priority area target for nature conservation can also be implemented in floodplains.

METHODS

Using freely available spatial data for Europe, we have identified spatial hotspots for floodplain protection, but also possible potentials for floodplain development, which make this area requirement concrete for the implementation of the European Biodiversity Strategy.

The majority of the data used in the following analyses are obtained from the Copernicus programme via the EEA data portal (e.g. ECRINS data), or are processed in national programmes and reported to European or other European institutions under various environment protection policies (e.g. the Habitats Directive). To assess the status of floodplains, spatial relations between available datasets have been established via attribute relations, intersections etc.

RESULTS and DISCUSSION

To get an idea where the remaining good floodplains are, but also where the potential area for floodplain restoration are, many spatial exercises and analyses have been done. The main spatial input data are the floodplain delineation according to the JRC modelled 500-year flood risk area, which is representing for us the morphological floodplain (river, active and former floodplain together) across Europe (Fig. 1). The layer is covering the political European Union, and neighboring countries. Russia, Belorussia, Ukraine and Moldova are examined.

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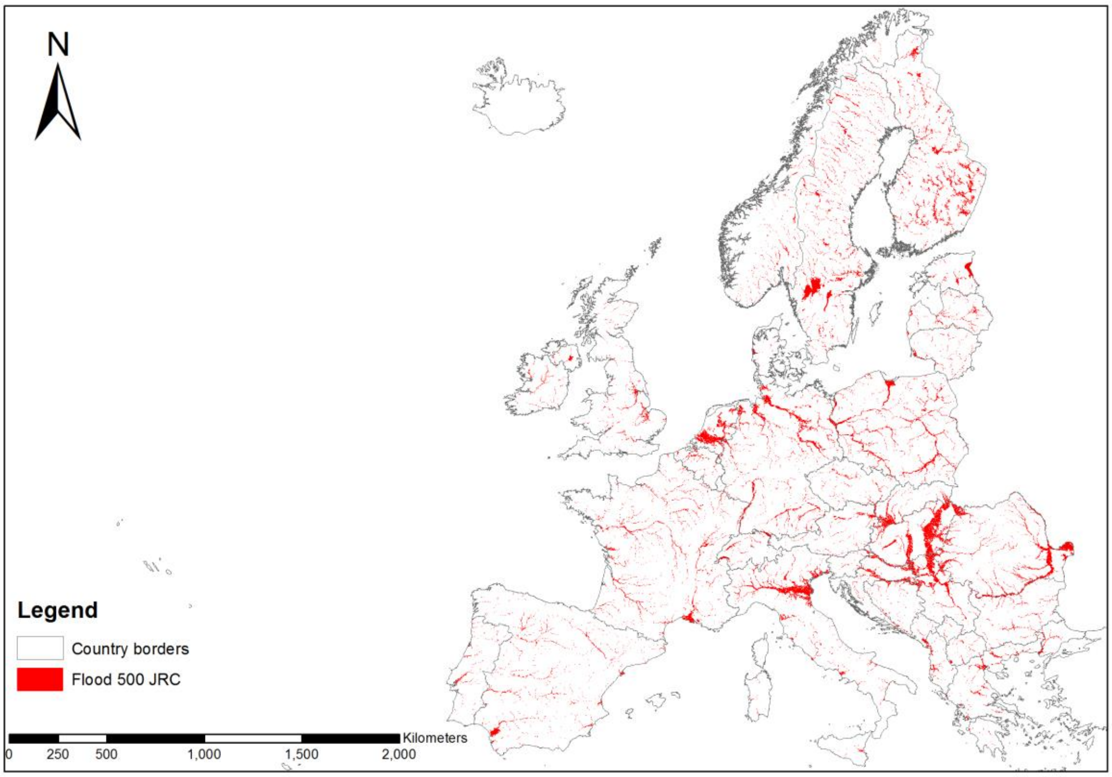

Fig. 1. Floodplain extent - modelled flood risk area with 500 year return period by JRC. The spatial basis for an assessment of the potential for floodplain restoration in Europe.

For Europe, approx. 4% of the land area is considered to be morphologic floodplains. It varies from country to country, in Germany it is about 6% of the terrestrial land area.

By intersecting the land uses, it was possible to calculate that more than two thirds of the floodplain areas are used intensively for agriculture and are often protected by flood protection measures. However, these are also the areas with a high potential for reconnection within the meaning of the new European Restoration Act, as studies already carried out to identify potential for reconnecting former floodplains in Germany have shown (Harms et al., 2018).

The presentation shows to what extent a proxi-based assessment for a floodplain condition is possible with available data and derives an initial area requirement for the restoration of natural floodplains for the area under consideration.

CONCLUSIONS

The conservation and wise management of still existing near-natural floodplains is crucial. The current designation of protected areas and NATURA2000-sites shows good coverage of floodplain areas that are valuable from a nature conservation perspective. Nevertheless, the conservation status of many species or habitats shows that there is still a great need for action here. The potential for possible floodplain development is present, as shown in the results of this study or by Harms et al. (2018) for Germany. Consistent use of existing environmental directives (FFH, WFD, etc.) and making use of existing experience is necessary. Improving the lateral connectivity of rivers and floodplains is an essential prerequisite – not only dyke relocations but also a large number of structural measures are necessary to ensure that high river discharges reach the floodplains again.

If 20% more ecologically functional floodplains are to be generated in the coming years, they must be developed from agricultural land. This often involves very fertile soils and can, therefore, in many cases inside the European Union only be realized with the Common Agricultural Policy (CAP), i.e., in close cooperation with the farmers. Since the management of floodplains is associated with major challenges and the financial resources are likely to be excessive, priorities must be set. This contribution is a work in progress and should result in a manuscript in the course of the year.

ACKNOWLEDGEMENTS

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Transformative change for wetlands: learning the lessons from communities to governments

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INTRODUCTION

"Transformative change in all parts of society and our economy is needed to stabilize our climate, stop biodiversity loss and chart a path to the sustainable future we want. This will also require us to address both crises together, in complementary ways." - Ana Maria Hernandez Salgar, Chair of IPBES.

We are at a uniquely critical moment in history, as ecosystems and biodiversity, including wetlands, degrade, disassemble, and disappear, despite decades of conservation and restoration efforts. Many global governance and NGO institutions, scientists, and Indigenous Peoples and Local Communities are calling for transformative change. In many places around the world, communities are instituting and defending the Rights of Nature, including the Rights of Wetlands, as a means of transforming our relationship with Nature/wetlands from one of extractivism to one that recognizes the rights of Nature/wetlands to exist, to have a place to exist, and to function as part of the Earth's natural processes. Wetland science, practice and policy can inform, and be informed by, a Rights of Wetlands mindset, culture, and policy/legal framework, resulting in a shift in the paradigm of how we humans understand, relate to, and manage wetlands, thus supporting more effective wetland science, conservation, restoration, and management.

METHODS

Implementing Rights of Wetlands (ROW) as a way of promoting socio-ecological resilience and adaptation, requires moving away from a dualistic world view that places people outside of and above Nature and instead moves towards the understanding that humans are one of many species in wetland ecosystems and an equitable relationship among all species, processes and ecosystem structure is required. For communities that do not already have this type of relationship with nature a ROW approach requires a cultural and behavioural shift to a position where the right of a wetland to exist and to function naturally is respected. Numerous examples of legal recognition of ROW and the living beingness of wetlands are emerging but what does implementing ROW mean in practice for governments, communities and their wetlands?

Much of the recent growth in contemporary formal recognition of the Rights of Nature draws on improved understandings about the belief systems and traditional practices of Indigenous peoples and local communities (IPLCs). The cultural and linguistic heritage of IPLCs contributes to the world's diversity. Their knowledge and practices have enhanced respect for the environment and natural resources, often offering models of sustainable approaches to water security, food security, health and well-being. Traditional knowledge and management practices often play a significant role in protecting crucial habitats and the socio- ecological systems they support.

The identification and sharing of wetland best practice from IPLCs, that implement a ROW approach, can help support governments and communities that want to develop an equitable, healthy and sustainable relationship with nature. A Darwin Initiative, UK Government, funded project entitled "Rights of Wetlands Operationalisation for Biodiversity and Community Resilience" is exploring how Rights of Wetlands can be implemented by governments as national policy, legislation and governance and by communities and stakeholders through actions at specific wetlands in Ecuador, Bolivia, Guyana, Sri Lanka and Kenya.

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RESULTS and DISCUSSION

The five different countries and wetlands provide very different contexts in terms policy and governance, political systems, acceptance of Indigenous Peoples' worldview and rights, wetland types and urban and rural locations. These contexts influence the acceptance and ability to shift to a Rights of Wetlands approach.

Bolivia

The probability of Bolivia adopting a wetland rights approach is significant due to its existing legal and political framework, as well as community participation and environmental awareness. Undoubtedly, the existence of the "Law of Mother Earth's Rights" in Bolivia demonstrates a legal commitment to recognizing the rights of nature. This provides a basis for adopting a similar approach regarding wetlands. However, the effective implementation of existing legislation can be a challenge due to the need to establish clear mechanisms for enforcement. The lack of financial and human resources could hinder effective implementation. Bolivia has a rich diversity of cultures and communities with active and visible voices in society. Direct communication and participation of these communities is essential for the success of a wetland rights approach.

Ecuador

The Rights of Nature article in the Ecuadorian Constitution reflects the beliefs and traditions of the Indigenous Peoples of Ecuador, declaring that nature "has the right to exist, persist, maintain and regenerate its vital cycles, structure, functions and its processes in evolution." This right, the constitution states, "is independent of the obligation on natural and juridical persons or the State to indemnify the people that depend on the natural systems." While various governments have largely ignored the rights of nature in favour of extractive policies the Rights of Nature article in the Ecuadorian Constitution exerts practical jurisdiction over all natural elements and it is especially protective of vulnerable ecosystems.

The rulings of the Constitutional Court regarding the rights of mangroves and the Los Cedros bioregion to exist in-of-themselves independently of the services they may offer human communities is a case-in-point, which set a new legal, political and cultural environment that is fully supportive of initiatives based on a Rights of Wetlands approach. This pro-nature legal environment has also been strengthened by the fact that in the last few years more than 75 laws and regulations in Ecuador have been amended to incorporate the rights of nature and that a dozen court cases have addressed these rights.

Ecuador's legal framework supports actions protective of the Rights of Wetlands and the rights of Indigenous communities to make decisions about the bodies of water within their territories. The recent referendum banning oil drilling in the Yasuní National Park is a clear indication that the Ecuadorian civil society has engaged in a robust dialogue about the Rights of Nature and Water both in mainstream media and alternative media venues.

Guyana

Guyana has shown a commitment towards the protection and conservation of its environment through the various international agreements and national legislation and policies developed over the years. The country does recognise the importance of the ecosystems and their ecological value to fighting climate change. In the long run these actions will ensure that the integrity of these systems may remain intact but more work would have to be done to ensure that objective is met. Currently there is no policy or legislation in Guyana that supports the Rights of Nature so a significant political and cultural shift is required to transform current legislation.

Indigenous Peoples and Local Communities in Guyana have always used their resources based on their traditional knowledge and practices within their cultural norms. Governmental policies have now been added to the mix. They therefore seek ways to mesh traditional practices and policies driven by a more scientific approach. The communities have always acknowledged the values, significance and economic benefits that wetlands provide but communities lack the capacity to plan resource use and management from their standpoint and are under pressure to pursue an economic development model.

Kenya

Lack of a holistic institutional framework has affected wetland management in Kenya as noted in the Environment Policy and the Wetlands Policy. Different aspects of wetland conservation and management are handled by different agencies. This has therefore meant that no single agency is in charge of overall coordination. This has contributed to massive wetland loss and degradation. The Kenyan Government has undertaken reforms aimed at conservation of environmental resources including wetlands. Two key institutions charged with mandates to manage wetlands are the National Environment Management Authority (NEMA) and the Kenya Wildlife Service (KWS).

Opportunities for adoption of Rights of Wetlands approach include the requirement under The Environment Management and Coordination (Conservation and Management of Wetlands) Amendment Regulations, 2017 that provide for the development of Integrated Wetlands Management Plans to prevent and control further degradation of wetlands in Kenya. Mainstreaming Rights of Wetlands in the Regulations will ensure adoption of the Rights of Wetlands in the Country.

Sri Lanka

The rights of nature concept is deeply embedded in varying extents in Sri Lankan culture, history and religious groups. Hence, integrating this concept into the legal and policy framework governing Sri Lanka's wetlands may be possible. Sri Lanka has multiple legislations that contain provisions for the protection of the wetlands, there is no single legislative provision that explicitly recognizes wetlands, or selected wetlands to be legal persons with corresponding rights. While the discourse surrounding the rights of nature is surfacing in Sri Lanka, there lacks any authoritative legal instrument—whether constitutional, legislative, judicial, or otherwise—that acknowledges any aspect of nature, or nature in its entirety, as possessing inherent legal rights.

Elements of rights of nature can be found within the historic, cultural, and religious views and aspects of communities in Sri Lanka, however this is interlinked with human connection to nature. The distinction between connectedness and rights of nature may need to be identified and articulated for further clarity in the Sri Lankan context.

CONCLUSIONS

The political, social, cultural and environmental contexts influence the acceptance and ability for governments and communities to shift to a Rights of Wetlands approach. Lessons learned from this work will assist other governments and communities to move to a more respectful and equitable relationship with nature and wetlands.

ACKNOWLEDGEMENTS

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SOCIETY of WETLAND SCIENTISTS
Europe Chapter

POSTERS

POSTERS

How many peatlands and mires in Belarus?

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INTRODUCTION

Belarus has a variety of peatland types representative for temperate lowland in Europe. Belarus is among the leaders in peatlands conservation, drainage and restoration. Proper peatlands inventory is a prerequisite to their wise management and conservation. There are significant discrepancies in the estimation of the total area of peatlands and mires in Belarus. We aimed to (1) compile existing data about peatlands distribution (focusing on mires) into the most recent and comprehensive peatlands database and assess the total peatlands area in Belarus; (2) asses the condition of the recognized peatlands, their current conservation status; (3) systematize available information on the peatlands rewetting/restoration activities in Belarus during the period 2005-2023 and (4) present the current state of the peat extraction in Belarus.

METHODS

Firstly, to update the estimate of the current area of mires in a natural and near-natural state, we analyzed and merged information from two databases: the database of mires with an area of more than 50 ha prepared by APB-Birdlife International in 2009-2011 and the peatlands database created by the National Academy of Science in Belarus (“Peatlands of Belarus” database, 2016). From the latter, we extracted only the natural peatlands from the layers “mires” and “for peat extraction”. Duplicated areas were excluded, the boundaries were edited where necessary.

Secondly, we added the areas of mire habitats registered for protection (a national form of nature conservation), if not covered yet. Finally, we supplemented the database with mire areas identified remotely using Google Earth images, crosschecked with available cartographic and taxation material of the State Forestry Institutions (Forest cadaster, 2024). This database included both mires and some disturbed peatlands, where mire vegetation recovered fully or partly.

To obtain information on conservation status and current management of the peatlands in Belarus we used recent maps of the nationally and regionally designated conservation areas as well as the global datasets on land cover (Zanaga et. al. 2022).

The peat extraction statistics were from the web-site of National Statistical Committee of the Republic of Belarus www.belstat.gov.by. However, some data ware closed for public use after 2020. Later data were gathered from the interviews with official persons available on the Internet.

The information about restoration projects was systematized from the official projects reports publicly available on the Internet, supplemented from the news media. The dataset consists of site name, location with coordinates, type of peatland and its total area, land use before restoration, stress factor, as well as restoration area, applied restoration method, monitoring data, year of restoration and financing sources.

RESULTS and DISCUSSION

The total area of peatlands in Belarus varies in assessments (Tab. 1). We managed to establish the boundaries of more than 2000 mires on the total area of about 1.3 million ha. The database includes both mires preserved fully in their natural state and disturbed areas that still hold mire vegetation, as well as some previously drained peatlands on which mire vegetation has now fully or partially recovered. However, we consider this number is still underestimated, as it does not include small mires (less than 50 ha), a significant part of native deciduous mire forests (alder), as well as a part of spontaneously restored drained peatlands. We estimate that the total area of mires in Belarus can be 1.5 - 2 million ha, including 400-500 thousand ha of open mires. The Forest Cadaster (2024) of Belarus provides data on 2.4 million ha of forested peatlands and mires.

Table 1. Assessments of peatlands area in Belarus by different authors.

	Yurkevich and Golod, 1981	Strategy ..., 2015	"Peatlands of Belarus" database, 2016	Grummo et al., 2021	Our assessment
Total area of:	[10^3 ha]				
peatlands	3931,4	2381,7	2674,8	2939,0	-
mires	2580,9	863,0	926,8	863,0	1500-2000
drained peatlands	1350,3*	1592,6	1728,5	1939,7	1700-1850

** ha 1979 r.*

We calculated that around 50% of mire area has a (formal) conservation status, i.e. is located within areas nationally or regionally designed for nature conservation. The majority of mires of Belarus are forested (77% of the area, mainly alder, birch and pine), while drained peatlands are quite equally divided between forests, grasslands and arable land.

Each year 20 peat extracting companies in Belarus extract over 2 mln tonnes of peat, ca. 90% is for fuel. 99,1 thousand ha of peatlands are planned for peat extraction in 2016-2030, while 281,5 thousand ha are depleted peat extraction sites (*Strategy...*, 2015). According to the Ministry of Energy of Belarus, the country ranks first in the world in fuel peat briquette production volumes. In 2020 the Programme of Complex Modernisation of Peat Production Facilities for 2021 – 2025 was approved in Belarus. It should ensure continued use of peat for fuel (also for cement production) and to expand the use of peat for horticulture (growing champignons considered as promising direction) and fertilisers. Over 90% of the extracted peat is used in the country, while 6-12% are exported.

Large-scale peatland fires on abandoned peat extraction sites in 2002 became a trigger for peatlands rewetting projects in Belarus, which were fully financed by international funds, largely by UNDP/GEF. By 2023 over 80 000 ha are reported as rewetted/restored peatlands, ranking Belarus as a leader on peatlands restoration in Europe. The majority of rewetted sites were depleted areas after peat extraction, where drainage was blocked through the installation of dams at intervals along the length of each drain. Only Dzikaje (330 ha) and Dziki Nikar (1200 ha) were rewetted after agricultural peatland use. By the time of rewetting, both sites were included into the lands state nature conservation institution Belawiezhskaja Pushcha National Park. Drain-blocking was also applied on the sites drained for forestry: Červień-2, Hałoje, Vieračskaje and Žada (partly). Reported as successfully restored peatlands, most of the sites were flooded and became shallow lakes. Besides, many extracted peatlands rewetted spontaneously due to neglection of drainage maintenance or/and thanks to the beavers. The data about the scale of the spontaneous rewetting is missing. Moreover, occasional peatlands vegetation management (tracked mowing, burning) within nature conservation areas was reported as restoration in Zwaniec, Sporauskaje, Siervieč, Dzikaje peatlands.

CONCLUSIONS

The total area of peatlands and mires in Belarus seems to be highly underestimated in the national reports and recent publications.

International financial resources were used to rewet manly depleted peat extraction sites. At the same time, the state aims to develop peat extracting industry, which threatens natural mires to be drained and the peat to be mainly burned as fuel. The total rewetted area in years 2010-2023 is comparable to the area planned for peat extraction in 2016-2030.

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POSTERS

Chemical characteristics of water of petrifying springs (*Cratoneurion*)

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INTRODUCTION

Petrifying springs (*Cratoneurion*) are formed chemically or biologically from the decalcification of karst waters (Lyons and Kelly 2016). This process only takes place where the geological substrate is composed of rocks containing calcium carbonate in various volumes and forms, and the pH ranges from 6-9 (Krause et al. 2015). The aim of our research was to determine the chemical properties of water from Petrifying springs (*Cratoneurion*). We assume that the ionic composition of water from Petrifying springs (*Cratoneurion*) is significantly different from water without travertine deposit.

METHODS

Five different petrifying springs (*Cratoneurion*) were analyzed in the Sucha Forest District. Petrifying springs (*Cratoneurion*) were inventoried in detail in the field. Water samples were taken from each petrifying spring (*Cratoneurion*) in several places for detailed analyses. Samples were taken at the beginning of the spring, in the middle part and at the end. Similarly, samples were taken from springs without travertine deposits. The pH and ionic composition of the obtained filtrate were determined. The filtrate samples chemistry was analysed by ion chromatography using a DIONEX ICS 5000 unit equipped with a DIONEX AS18 anion column and a DIONEX CS16 cation column. The analytical columns were used to simultaneously determine the cations and anions in the same water sample. Additionally, pH was determined by a multifunctional computer instrument CX-741 Elmetron.

RESULTS and DISCUSSION

The laboratory analyses confirmed the unique chemistry of water from petrifying springs (*Cratoneurion*) (Podgórska et al. 2016). Water from these sources has a significantly higher pH and electrolytic conductivity. Water from petrifying springs (*Cratoneurion*) was characterized by a significantly higher content of F, Br and SO_4 anions with a significantly lower content of nitrates (in selected cases 20 times lower content). In the studied petrifying springs (*Cratoneurion*), the concentrations of Ca, K, NH_4, NO_3, F, Br and SO_4 decreased with increasing distance from the outflow site.

The factors favoring the precipitation of travertine deposit are obstacles in the form of thresholds causing water turbulence (Lyons and Kelly 2016). The presence of deadwood and vegetation initiates the formation of travertine deposit. The plant communities developing along the petrifying springs (*Cratoneurion*) are similar to *Caltho-Alnetum* with a strong development of the moss layer. The threat to petrifying springs (*Cratoneurion*) is disrupting of the continuity of the soil cover in the immediate vicinity. In the area with petrifying springs, forest management should be carried out with particular caution, logging routes should be avoided and the complex structure of the tree stand should be preserved.

POSTERS

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POSTERS

Preliminary quantification of Greenhouse Gas Emission in the Biebrza River Floodplain

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INTRODUCTION

To better understand how global climate change will affect greenhouse gas dynamics, accurate quantification of global greenhouse gas emissions from these areas is essential. As the accumulation of carbon dioxide (CO_2), methane (CH_4), and other greenhouse gases (GHGs) in the atmosphere continues to increase global average temperature, understanding and quantifying fluxes to and from various environments has become a high priority. (Bass et al., 2014). Riverine systems are intricate systems where the floodplain, the boundary between aquatic and terrestrial environments, is crucial for certain ecosystem functions (Machado dos Santos Pinto et al., 2020). Therefore, floodplains are critical ecosystems that can act as significant sources of GHGs. Accurate estimation of GHGs is essential for understanding their role in climate change and management strategies (Webb et al., 2016). The Biebrza River is a notable example where the impact of the climate change can be assessed. This study leverages water table data and an empirical formula from previous research to estimate the flooded area and uses two years of GHG measurements to calculate emissions.

METHODS

Flooded Area

To calculate the flooded area (km^2), the water levels (cm) measured daily from 1947 to 2022 were used as raw data. For this, an empirical formula from a previous study (Grygoruk et al., 2013) was used:

$$y = 0.0005x^2 + 0.4081x - 138.11$$

Where x is the water level (cm) and y is the flooded area (km^2).

Emission calculation

Emission factors were used to calculate the emissions of CO_2 and CH_4. These emission factors were derived from the literature (Cassanaz et al., 2022). For CO_2 the emission factor is 0.31 (t C/hectare). Then, it was necessary to convert the amount of carbon to metric tons of CO_2. Since the ratio of carbon to CO_2 is 1:3.67 (one molecule of CO_2 contains one carbon atom and two oxygen atoms), multiply the amount of carbon by 3.67 to obtain the amount of CO_2 emitted (Romm, 2008). For CH_4 the emission factor is 2.5 (kg CH_4/hectare). For both gases, the same formula was used:

$$CO_2/\,CH_4 = Flooded\ area * Emission\ factor$$

To compare the CO_2 equivalent with the CH_4 Global Warming Potential (GWP) is used. Which value is 25 kg of CO_2 Eq/kg of CH_4, recommended by the IPCC (2007), during a specific period of 100 years.

POSTERS

RESULTS and DISCUSSION

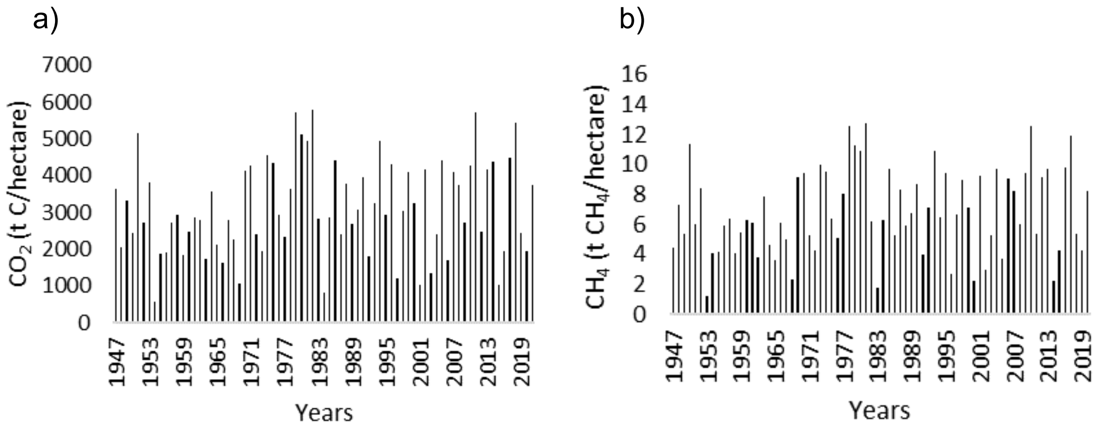

Fig. 1. a) CO_2 Calculated with the emission factor and flooded areas from 1947 until 2022.
b) CH_4 Calculated with the emission factor and flooded areas from 1947 until 2022.

A constant fluctuation of CO2 can be observed during the study period. However, a slight decrease can be observed from 1954 to 1968. CH_4 values present a constant change during the study period. Where the highest emissions can be observed during the year 1950, the period from 1978 to 1981, as well as high peaks during the years 2010 and 2017. Furthermore, it can be seen that CH_4 emissions do not follow a constant increasing or decreasing trend.

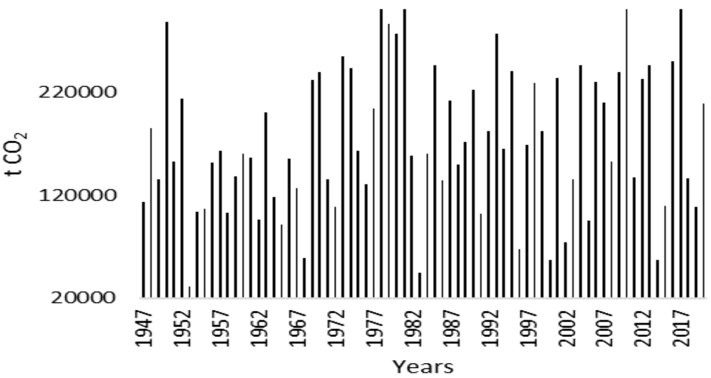

Fig. 2. Comparison of CO_2 equivalent with CH_4 from 1947 until 2022.

The total emission of CO_2 equivalent in the floodplain on average is 174436 tones annually. Between 0.5 and 1 gigatonnes of CO_2 are already released from degraded peatlands annually. This accounts for about 5-10% of the global annual anthropogenic CO_2 load that enters the atmosphere (Lamentowicz, after Tomala, 2021). In comparison with the value found in this research, peatlands emit more CO_2 than floodplains. This could be due to their anoxic nature, therefore, restoring disturbed and degraded peatlands is an emerging priority in efforts to mitigate climate change (Loisel & Gallego-Sala, 2022).

The empirical formula indicated that the flooded area varied significantly with changes in water table levels, ranging from 487 to 5100 hectares across the studied period. Utilizing water table data as a main indicator for determining flood area is a methodologically sound choice (Grygoruk et al., 2013). The application of the emission factor to estimate CO_2 and CH_4 is a fundamental step in the evaluation of GHG contributions. An emission factor provides a useful shortcut for the quantification of GHGs. (Wood & Cowie, 2004). That is why there are limitations inherent in using generic emission factors, as these may not fully capture the complexities of site-specific biogeochemical processes. This could lead to significant uncertainties and will require additional data and validation for more precise results.

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CONCLUSIONS

The calculated average area of the floodplain in Biebrza is 2 741 ha, meanwhile the peatlands cover an area of 45 000 ha. In the degraded peatlands, 0.5-1 gigatonnes of CO_2 are already being released annually, meanwhile, according to the calculations, the floodplains emit 0.000174436 gigatons of CO_2. The methodology used in the study provides a valuable initial approach to estimate the flooded area and therefore the GHG emissions, using the emission factor for each gas. However, significant improvements in the accuracy of the estimates are needed, since the data used is not enough to have an accurate result. Since GHGs depend on several factors: climatic, and hydrological. Incorporating more specific and detailed data, will provide better results. Moreover, finding a methodology where other factors like soil composition, vegetation, air temperature and wind speed has to be performed in other to obtain quality data and have an understanding of GHGs in the study area.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisors Mateusz Grygoruk and Anna Sieszko for their invaluable assistance and guidance in handling the data for this research. Their expertise and support have been instrumental in ensuring the success of this endeavor.

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POSTERS

Rewetting 100.000 ha of lowland organic soils in Denmark

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INTRODUCTION

In October 2021 the political parties in the Danish parliament made a broad political agreement with concrete actions to secure a reduction of 1.9 mill. tons of CO2e in 2030. But the ambition for the parliament was to reduce the CO2e with 8 mill. tons in 2030 through technological developments. Specifically, reduction of CO2e from low-lying organic soils was set to 0.5 mill. tons in 2030 (i.e. 38.000 ha organic soils), and again further initiatives should provide 0.2 mill tons CO2e (i.e. 12.000 ha organic soils). While the overall ambition was that 100.000 ha of low-lying soils should be rewetted concrete plans were made for 88.500 ha of which 50.500 ha should be rewetted and 38.000 ha soils in crop rotation converted to more extensive grassland management plus an option for additional 12.000 ha. The total area of organic soils in agricultural use in Denmark is shown in table 1. The total budget allocated to land use changes of low-lying organic soils was 620 million Euro.

Rewetting of low-lying organic soils entails several challenges which must be addressed. Agricultural practices including drainage have often resulted in high topsoil nutrient contents and irreversible changes in hydrology (e.g. flow paths, hydraulic conductivity, and loss of water buffering function (water storage) due to mineralization, compaction, and decomposition of peat.

Since not all these low-lying organic soils are situated in river valleys or act as riparian areas there is some uncertainty regarding their ability to remove or retain nutrients. Thus, The Danish Agricultural Agency and The Danish Environmental Agency have funded a research program aiming at elucidating how these low-lying organic soils – also including remnants of raised bogs – handle nutrients both before and after rewetting.

SITE SELECTION

We have selected five different wetland sites (Fig. 1, Tab. 2) representing different wetland typologies with the purpose of describing changes in nutrient concentrations, water and mass balances before and after rewetting. A technical feasibility study (TFS) is mandatory for getting funding for all Danish wetland restoration projects. This TFS includes spreadsheet tools for calculating the expected reduction in CO_2 emission, nitrogen retention and risk of phosphorus leaching after rewetting (Tab. 3).

INSTRUMENTATION

The five sites have been instrumented with flowmeters at points of discharge entering or leaving the wetlands by means of electromagnetic flowmeters, V-notch weirs or Doppler flowmeters. Piezometer transects and nests have been established and at the same time soil profile descriptions and soil sampling were made. Pressure transducers were installed in selected piezometer nests for online logging of groundwater level as a supplement to manual measurements. Grab samples of surface and groundwater water were collected every third week or continuously with automatic samplers (ISCO samplers).

RESEARCH AND MONITORING ELEMENTS

At all five sites basic measurements include groundwater level, hydraulic conductivity, stage discharge stations or Doppler measurements. Soil samples are analyzed for bulk density, loss on ignition, and contents of C, Fe, N, P, and S. Also, geophysical measurements have been made including towed, ground-based transient electromagnetic-measurements (tTEM) and borehole logging of nuclear magnetic resonance (BNMR) (e.g. SR Mashhadi et al, 2024). Groundwater and surface water are analyzed for all N and P species, SO_4, TOC, DOC, Fe and Cl. Water and mass balances are currently being calculated for the before and after situation or will be calculated depending on where in the process the wetland in question is.

At some of the sites additional research takes place, e.g. preventive measures such as topsoil removal and harvest of biomass are investigated.

All data will go into a toolbox to be used for further data processing, analysis and modelling aiming at providing optimal advice to the administrative agencies in DK.

Preliminary results indicate a large variability in the effect of rewetting on nutrient retention between the investigated areas, ranging from barely detectable changes to large increases in retention of both nitrogen and phosphorus.

Fig. 1. Location of the five monitored sites in Denmark.

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Table 1. Area and land use of low-lying organic soils in agriculture divided between soils with 6 – 12 % carbon and more than 12 % carbon.

Land use	6 – 12% C [ha]	> 12% C [ha]	Total [ha]
Permanent grass	20.244	21.952	41.836
Crop rotation	66.973	39.318	106.292
Other crops	10.525	12.354	22.880
Total	97.743	73.264	*171.007

**Latest: only 118.000 ha left (reported by M. Greve, 7/12-2023, Danish radio and Ritzau).*

Table 2. The five selected sites being monitored before and after rewetting.

Project	Type	Area [ha]	Status
Ringfenner	Raised bog	345	Rewetted summer 2023
Strande Enge	Percolation mire and coastal wetland	20	Rewetted June - August 2022
Vosborg Enge	Floodplain and percolation mire	102	Rewetted February-April 2024
Runkenbjerg	Spring mire and percolation mire	19	Rewetted October 2017
Lobæk	Fen and percolation mire	212	Rewetted 26 April 2022

Table 3. Desktop calculation of reduction in CO_{2e} emission and N removal after rewetting of the five sites. The phosphorus risk analysis is not shown.

Project	Reduction [tons CO_{2e}]	N removal [kg N $year^{-1}$]	N removal [kg N ha^{-1} $year^{-1}$]
Ringfenner	4833	1621	5
Strande Enge	346	2017	102
Vosborg Enge	1415	3960	45
Runkenbjerg	395	838	45
Lobæk	3479	14367	65

CONCLUSIONS AND FUTURE EXPECTATIONS

Expectations of positive outcomes of taking low-lying organic soils out of crop rotation are plentiful. These include increased carbon sequestration, reduced emission of greenhouse gases, a stop of the use of pesticides in the rewetted areas, as well as increased retention of nutrients and mitigation of nutrient transport to downstream recipients. In addition, expectations are that biodiversity (plants, insects, soil fauna, birds etc.) will improve over time as well as the drinking water quality (groundwater). Furthermore, the restored sites may improve water storage capacities.

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POSTERS

Issues of Peatland Restoration Across Scales: Hydrological Consequences and Knowledge Gaps – a Review

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INTRODUCTION

Peatlands are critical ecosystems that play a significant role in global carbon storage, water regulation, and biodiversity conservation (Leifeld & Menichetti, 2018). However, they are increasingly degraded due to anthropogenic activities such as drainage, agriculture, and peat extraction, leading to significant carbon emissions and loss of ecosystem services (Joosten et al., 2012). Restoration efforts, particularly re-wetting and re-vegetation, have been implemented globally to reverse these damages and restore the ecological functions of peatlands (Parish et al., 2008). Despite these efforts, the effectiveness and outcomes of peatland restoration vary widely across different scales and regions. This variability is influenced by factors such as local climate, hydrological conditions, and initial degradation states, which necessitate tailored restoration approaches (Minayeva et al., 2020). Furthermore, there are substantial knowledge gaps in understanding the long-term ecohydrological consequences of these restoration practices (Sirin et al., 2020).

This review aims to synthesize current knowledge on peatland restoration across various scales, highlighting the hydrological outcomes and identifying critical gaps in our understanding. By doing so, it seeks to inform more effective and sustainable restoration strategies that can be adapted to diverse ecological and climatic contexts globally (Page et al., 2011).

METHODS

This review integrates a literature review and meta-analysis. Systematic searches in Web of Science, Scopus, and Google Scholar focused on studies from 2010-2023 using keywords such as "peatland restoration," "re-wetting," "hydrological impacts," and "biodiversity." For the meta-analysis, data on pre- and post-restoration water table levels were extracted from studies providing sufficient statistical detail. The meta-analysis was conducted using RStudio, employing a random-effects model to account for study variability. Heterogeneity was assessed using I^2 and τ^2 statistics, and potential sources of heterogeneity were explored through subgroup analyses.

RESULTS and DISCUSSION

The forest plot reveals that peatland restoration efforts, particularly through re-wetting, significantly raise water table levels across various global sites. The mean difference (MD) in water table depth before and after restoration is consistently negative, with the common effect model indicating an overall MD of -0.76 [95% CI: -0.80 to -0.73] and the random effects model reporting an MD of -0.80 [95% CI: -0.87 to -0.73]. Both models present highly significant p-values (< 0.0001), strongly supporting the efficacy of peatland restoration in reducing water table levels. This means that after restoration through rewetting, the water table tends to decrease significantly. These results are supported by the conclusion from the random effects model, indicating that the decrease in water table levels is not specific to one location or condition but is generally observed across various sites studied.

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Despite the overall positive trend, the heterogeneity index (I^2 = 69%) indicates substantial variability among the studies, suggesting that the impact varies depending on factors like initial degradation states, local climatic conditions, and specific restoration practices (Sirin et al., 2020). This high heterogeneity highlights the need for tailored restoration approaches that consider local conditions to optimize outcomes. Further research is essential to refine these techniques and ensure the long-term sustainability of restored peatlands. The consistent positive outcomes across diverse studies validate re-wetting as a critical method for peatland restoration, although local adaptations and continuous monitoring are necessary to address the observed variability and enhance the effectiveness of these efforts.

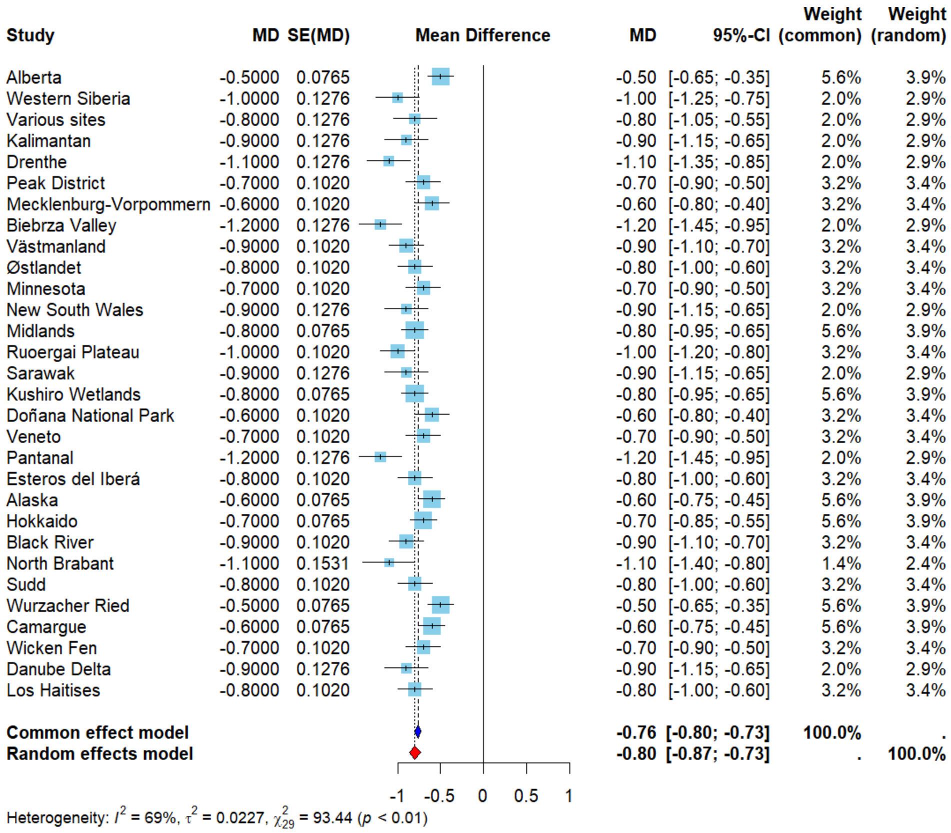

Fig. 1. Forest plot illustrating the mean difference (MD) in water table levels (in meters) before and after peatland restoration across various global sites.

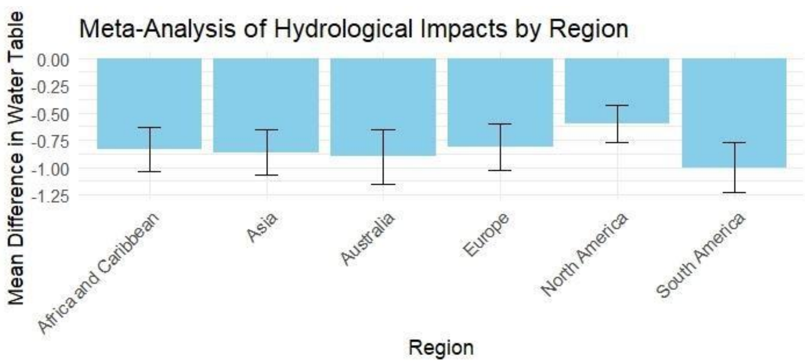

Fig. 2. Meta-Analysis of Hydrological Impacts by Region:
Mean Difference in Water Table Levels Before and After Peatland Restoration

Each region consistently shows a negative mean difference, indicating an increase in water table levels post-restoration, which underscores the overall effectiveness of re-wetting techniques in enhancing hydrological conditions. However, the graph also highlights regional variability. For instance, South America exhibits a greater rise in water table levels compared to other regions, suggesting that specific environmental conditions may amplify the effectiveness of restoration practices. In contrast, regions like Africa and the Caribbean display wider confidence intervals, reflecting greater variability in study results and possibly indicating differing levels of restoration success or variability in implementation practices. Continuous monitoring and adaptive management are crucial to address these variabilities and enhance the long-term sustainability of peatland restoration initiatives.

CONCLUSIONS

The review and meta-analysis demonstrate that peatland restoration, particularly through re-wetting, significantly improves water table levels, which is crucial for restoring natural hydrological conditions. The mean difference (MD) in water table depth consistently shows positive results. However, substantial heterogeneity (I^2 = 69%) indicates that outcomes vary based on factors such as initial degradation states and local climatic conditions. This highlights the necessity for tailored restoration approaches and continuous monitoring to optimize hydrological outcomes. Future research should focus on refining these methods to ensure the long-term sustainability and effectiveness of peatland restoration efforts.

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POSTERS

The impact of oil shale mines on the development and carbon storage of a raised peat bog in Estonia: pollution, drainage and climate change

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INTRODUCTION

Our research project, recently initiated, aims to investigate the impact of both atmospheric pollution resulting from peat exploitation and land improvement, as well as climate change, on the Liivjärve peat bog located in the Kurtna Lake District of Estonia. Peatlands play vital ecological roles, such as carbon sequestration and biodiversity conservation, yet they are increasingly degraded due to human activities (Parrish et al., 2008). The study area, affected by industrial development, faces significant air and water pollution, impacting its ecological integrity (Koff, Arrhenius, 1992). Through multidisciplinary paleoecological analyses, including testate amoebae analysis, plant remains analysis and biogenic sediment chemical composition analysis, the project aims to reconstruct the historical impacts on the bog's condition, including those of industrial activities and climate change. The primary focus is understanding how shale exploitation contributes to pollutants in the peatland and its ecological consequences, including carbon accumulation rates.

Additionally, the research outcomes will shed light on the functioning of a peatland under significant anthropogenic pressure and changing climate conditions. These findings will complement ongoing studies on the anthropogenic influence in the Kurtna Lake District region. Preliminary results will be presented at the upcoming conference.

METHODS

For this study, two 100 cm long cores will be extracted from the Liivjärve peatland in Estonia (59.30765, 27.56926). Testate amoebae analysis will be conducted on 100 samples taken at 1 cm intervals from the first peat core, prepared according to Booth et al. (2010) method (2010). Carbon accumulation rate reconstruction will be based on peat bulk density analysis (Clymo et al., 1998). The second core will be scanned using a Geotek XRF scanner for quantitative elemental analysis, magnetic susceptibility, and high-resolution imaging (Longman et al., 2019). Age-depth modeling will be conducted using the OxCal application. Additionally, five samples of *Sphagnum* mosses from the first core will be dated using the 14C method at the Poznań Radiocarbon Laboratory (Walanus, Goslar, 2009).

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POSTERS

Fire history traced with molecular markers: identifying paleo and prehistoric fires in peat deposits near Lipsk archaeological site

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INTRODUCTION

Reconstructions of the fire history allow us to trace climate and environmental changes. The environment is impacted by several drivers, one of which is fire. The type of fire use and its consequences have been changing over the millennia. To better understand the functioning of nature and the environment it is necessary to perform interdisciplinary analyses, including fire chronosequence reconstructions in the paleoenvironmental studies.

The history of the paleoenvironment is stored in the deposit thanks to stable conditions, which promote the accumulation of organic matter in different stages of decomposition (Wieder et al. 2009). Specific organic compounds are stored within the organic matter (1) as products of its decomposition and/or (2) as compounds deposited, e.g. during the burning of the organic matter or forest fires. Peatlands have been broadly used in paleoenvironmental reconstructions in recent years including studies on fire history (e.g. Kong et al. 2021).

To reconstruct environmental changes, scientists recommend performing interdisciplinary analyses (e.g. Izdebski et al. 2016). Methods, which have been of particular interest in paleoenvironmental and paleoclimatic studies, are chemical analyses, including the identification of molecular biomarkers accumulated in different types of sediments. Besides fragments of carbonised wood–charcoal (e.g. Feurdean et al. 2017), molecular markers are also used, including polyaromatic hydrocarbons (PAH) (e.g. Kong et al. 2021) and n-alkanes (e.g. Berke 2018). The analyses of fire markers content (charcoals, PAH), together with markers of changes in the environment (n-alkanes) in peat deposits, enable obtaining various data about the time and location of the fire, as well as the composition of the burned organic matter.

Paleoenvironmental reconstruction has been an inseparable element of studies on prehistoric oecumenes and humans' adaptation to ongoing changes (e.g. Faith et al. 2015). Initially, in the Lower Paleolithic, hominids and hominins have been using fire on a small scale, usually for heating, protection (Shimelmitz et al. 2014; Gowlett 2016) and ritual purposes (Clark & Harris 1985; Pyne 2016). Although they have used fire since the Paleolithic, its greater impact on local environments became more evident in the Neolithic (beginning in Poland in 5400 BC). Around this time, some hunter-gatherers have undergone a different process – subneolithisation. This process is associated with changes in specific microregions (Wawrusiewicz 2022). As the Subneolithic groups were hunter-gatherers and mainly had a nomadic lifestyle, we pose the following research question: Did a contemporary human have a need and possibility to alter the surrounding natural environment to his liking?

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The north-eastern part of Poland is important for paleoenvironmental research, as traces of human activity have accumulated since the Late Pleistocene (Szymczak 1995). Within the Upper Biebrza Basin, an archaeological site in Lipsk is located on a dune surrounded by peatlands. This placement favours an intense accumulation of human activity traces. In previous archaeological and geomorphological research, it has been suggested that undisturbed sediments are present on the archaeological site in Lipsk (Frączek et al. 2020). Thus, such material consists of a consistent environmental record connected to human activity and settlement phases. The assumption is that the intensive activity of the prehistoric humans in this region has been strictly linked to fire use. Thus, peatlands near the archaeological site in Lipsk provide a unique prospect for verifying a hypothesis about the Subneolithic fire use by hunter-gatherer communities of the Upper Biebrza Basin in NE Poland.

It seems that the topic of (1) the connection between fire episodes occurring in the vicinity or on the peatlands and the settlement process, and (2) the impact of settlements on the surrounding environment in the context of fire use, is still not thoroughly studied. By including geomorphological and archaeological data in our study we will get a broader insight into the fire history and possible connections with prehistoric human activity near Lipsk. Thus, this project aims to analyse chosen fire markers, including charcoals and biogeochemical markers to trace fire history. Specific interest is focused on the transformation of the environment by the Subneolithic groups of hunter-gatherers in the vicinity of the archaeological site in Lipsk.

MATERIALS AND METHODS

For this project, we plan to extract peat core from peatland near the archaeological site in Lipsk. The peat core will be divided into samples and elementary analysis will be performed (loss on ignition, TC, TOC, TN, and C/N ratio), followed by fire and vegetation markers analysis (including PAH, n-alkanes, and charcoals). The charcoal quantification and identification will be performed using optical and SEM microscopes. The quantitative and qualitative analysis of PAHs and n-alkanes will be performed using gas chromatography (GC). The analyses will be conducted in the Laboratory of Biogeochemistry and Environmental Conservation in the Biological and Chemical Centre of Warsaw University.

As the project is in its initial state, this is an introduction to the research. The analyses are set to start in the second half of 2024.

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POSTERS

Impact of agricultural activity on vegetation, soil properties and soil seed bank of Krowie Bagno peatland (Western Polesie, E Poland)

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INTRODUCTION

Large-scale drainage for agriculture, forestry, and peat extraction for fuel and horticultural use during recent decades has severely reduced the areas of undisturbed mires in all European countries (Tanneberger et al. 2021). Their decline, estimated at 85% for Poland, 52% of Europe, and 15% on the global scale (Joosten & Clarke, 2002). Considering that peatlands provide multiple ecosystem services – water retention, floods and droughts prevention, nutrient removal, they are vast carbon sinks and stores, as well as habitats for wildlife, their restoration should be high priority of environmental protection in Europe in the next years. Given the complicated and challenging aim of not only re-wetting (aimed at reverse carbon emission), but also restoration of valuable habitats, studies of soil seed bank and soil properties should be an important step in this process.

A majority of mires in eastern Poland have been drained and transformed into grasslands. Studies show that due to irreversible changes in landscape settings, hydrology, soil and trophic conditions, the full restoration of them to natural mires is unlikely (Kreyling at al., 2021). Yet, an improvement of the ecosystem functions and revival of biodiversity in degraded fens seems possible (Klimkowska et al., 2010). It is estimated, that in the Western Polesie region approximately 75% of the natural peatland areas have been drained due to land reclamation activities conducted since at least the beginning of the 19th century (Chmielewski et al., 1996). The aim of this study was to determine the impact of melioration and agricultural activity on floristic composition of plant communities, and composition of soil seed bank of the largest degraded peatland in Western Polesie region (E Poland) - Krowie Bagno for its restoration perspective.

Krowie Bagno is an extent (3393 ha) complex of degraded fen with few remnants of decaying lakes in its eastern part. Its hydrological alteration was multi-stage process intensified at the end of 1960.. The effects of slight drainage became visible in the vegetation composition already in the early 1960’s. The peatland was then dominated by *Molinia* meadows with a high conservation value, with patches of fen communities still present near the lakes and at the verge of the peatland. Before its major hydrological alteration at the end of the 60s, Krowie Bagno was not only the largest, but also one of the most valuable natural areas of the Western Polesie, hosting many rare plant species (Olszewski et al. 1964, Łoś 1987). Drainage carried out at the turn of the 70s and 80s of the 20th century resulted in intensification of peat decomposition and decession. Consequently, nearly 30% of rare and protected plant species extinct, and the number of plant associations declined by half (Fijałkowski et al., 2000). Currently, about 88% of the study area of Krowie Bagno peatland is occupied by meadow communities (Sugier & Lorens, 2004), which replaced the previous seminatural plant communities as a result of land management (Jargiełło 1976).

METHODS

Seed bank analysis was preceded by a comprehensive historical analysis of Krowie Bagno peatland, utilizing maps, aerial photographs, and literature. Based on this, we focused the study on a part of the peatland that in the 1960s, prior the most intense phase of the melioration, exhibited dense patches of the *Molinietum caeruleae* community. Within this designated area, we established four plots representing varying degrees of anthropogenic transformation: A) purple moor-grass meadows moved once in year, B) purple moor-grass meadows, moved every 3-4 years, C) shrub community with dominance of *Betula pubescens* (formerly purple moor-grass meadows), D) meadow developed in the 1970s – drained mire, plowed peat, and grass mixtures sown (formerly purple moor-grass meadows). On each plot, 5 circular sub-plots with an area of 30 m^2 were randomly designated. Within these sub-plots we conducted phytosociological relevés and collected ten soil samples from a depth of 10 cm, which were then aggregated. Seed bank analyses were performed using the seedling emergence method. Following sieving and separation of plant roots, soil samples were placed in cuvettes and exposed outdoors. All emerging seedlings were identified, counted, and removed, and when identification posed difficulties, also transplanted and cultivated.

RESULTS and DISCUSSION

Replacement of the former semi-natural plant communities due to land management and agricultural activities has markedly influenced the floristic composition of plant communities and the soil seed bank of Krowie Bagno peatland. Mowing has notably increased species richness and diversity while reducing the occurrence of often expansive species such as *Betula pubescens*, *B. pendula*, and *Frangula alnus*. However, it has also led to a reduction in the occurrence of protected species like *B. humilis*.

Mowing significantly reduced the cover of *Molinia caerulea* as definitely dominant plant species in purple moor-grass meadows moved once in year in relation to purple moor-grass meadows, where mowing was abandoned over 20 years ago. In turn, the cover of *Carex davalliana, C. flava*, *C. panicea*, *Eriophorum latifolium* and *Succisa pratensis* in moved purple moor-grass was significantly higher than in other sites. Moreover, the presence such species as *Succisa pratensis* – the host-plant of the protected *Euphydryas aurinia*, and *Gentiana pneumonanthe* the host-plant of the protected *Phengaris alcon*, can certainly contribute to the enhancement of the population of these valuable and protected butterfly species.

Our research shows that scrub communities with dominance of *B. pubescens* (formerly purple moor-grass meadows) are characterized by the lowest species richness (phytocenoses composition, seed bank). The habitat conditions created by the emerging birch stand are not favorable for the species such as *Sanguisorba officinalis*, the host-plant of rare butterflies – *Diachrysia zosimi*, *Phengaris teleius*, and *Phengaris nausithous*.

The history of anthropogenic activity was also reflected in soil seed bank. *Potentilla erecta* was characterized by the highest frequency in the seed bank of all analyzed sites. The presence of *Molinia caerulea*, *Lythrum salicaria*, *Lysimachia vulgaris*, *Carex lepidocarpa*, *Mentha arvensis* was found in all assessed soil seed banks.

Diasporas of highly valuable species such as *Carex davalliana* and *C. buxbaumii* were exclusively found in purple moor-grass meadows moved once in year and those where mowing had been discontinued for over 20 years. Conversely, the diaspores of *Cardaminopsis arenosa*, *Cirsium arvense*, *Holcus lanatus*, *Festuca* sp., *Eupatorium cannabinum*, *Solidago gigantea*, *Alchemilla vulgaris*, and *Rumex acetosella* was characteristic only of meadows established in the 1970s following peatland drainage.

CONCLUSIONS

Meadow plant communities of transformed Krowie Bagno peatland still contain a relatively large local species pool (*Carex davalliana*, *C. buxbaumii*, *Schoenus ferrugineus*, *C. flava*, *C. lepidocarpa*), including a large and effective soil seed bank. Moreover, the presence of host-plants for the rare and protected butterfly species, can certainly contribute to enhancement the populations of this group. Therefore, the soil seed bank could play an important role in the restoration of this ecosystem. Field experiments taking into account physico-chemical soil properties are needed on optimal techniques for activating the soil seed bank of Krowie Bagno fen. In recent years, trees and shrubs have been removed from many peatlands in order to restore wet meadows and benefit from agri-environmental schemes. Our research shows that forest habitats are characterized by the lowest species richness (plant species composition, seed bank) and, therefore, should not be taken into account in the perspective of restoration.

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POSTERS

Unravelling human impacts on Norway's peatlands through paleoecological reconstructions

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INTRODUCTION

Peatlands cover 3% of Earth's land surface and store 25% (600 GtC) of global soil carbon, playing a vital role in local and global water and carbon cycles. These ecosystems, with unique flora, fauna, and microorganisms, preserve Europe's natural heritage. Unfortunately, human activities have increasingly impacted peatlands since the Middle Ages. Initially, minor disturbances like small settlements and limited forest clearings occurred. However, economic development led to deforestation, fires, drainage, and peat extraction, disrupting water conditions over the past 300 years. Anthropogenic climate change further threatens peatlands, causing rising temperatures that affect plant communities, hydrology, and microclimates. This forms feedback loops with climate change, earning drained peatlands the term "ticking climate bombs". Palaeoecological methods, such as testate amoebae analysis, help reconstruct past peatland conditions. These single-celled organisms build shells for protection and settle in peat, with species-specific shells aiding identification. Changes in amoebae communities reflect environmental disturbances, enabling the reconstruction of groundwater levels and geochemical variables in peatlands. Over the last three decades, significant progress has been made in developing testate amoebae-based transfer functions for many peatlands, mainly those located at lower latitudes. These features are critical tools used in creating paleohydrological reconstructions. Such hydrological transfer functions have not yet been developed for peatland areas in Norway, which constitutes a missing element in the scientific literature. Additionally, there are no published peatland-based quantitative palaeohydrological reconstructions from Norway in the multi-proxy context. Such studies need to be more robust to our understanding of the history and evolution of Norwegian peatlands. This lack of knowledge makes it impossible to effectively approach the protection and sustainable management of these unique ecosystems, especially in the face of the challenges of climate change and other threats.

METHODS AND PRELIMINARY RESULTS

Our research focuses on reconstructing the environmental history of peatlands to better understand how human activities and climate change have influenced these ecosystems. We present preliminary results from the Midtfjellmosen peatland in southern Norway, aiming to investigate the long-term effects of climate and land-use changes on water levels and vegetation. For this purpose, materials from three different research locations, obtained in August 2023 as part of the OPUS 21 grant, will be used. Two of these sites are located in the southern areas of Norway, in the Midtfjellmosen and Øvre Forra nature reserves. The third site, Suossjavri, is located in the northern Arctic Circle, characterised by a palsa-type landscape. As part of the analyses, samples of surface mosses were collected, and detailed research was conducted on the testate amoebae occurring on the surface of these peatlands. This comprehensive approach will enable the creation of a new training set and transfer function model for Norway. The newly developed model will also be used to reconstruct paleohydrological changes that occurred during the development of the Midtfjellmosen peatland. The reconstruction of groundwater level changes will identify the human impact on this peatland. It will allow for assessing whether the observed changes are related to global warming, an essential issue for the sustainable management of this unique ecosystem.

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