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DEAR PARTICIPANTS OF THE WETSCAPES CONFERENCE,

On behalf of the government of Mecklenburg-Western Pomerania, it is my pleasure to welcome you to the WETSCAPES Conference in Rostock. This conference brings together researchers from various disciplines and practitioners, working on any type of fen peatland or on coastal wetlands – pristine, artificially drained and rewetted. The protection of peatlands is important with regard to climate change mitigation, as well as wider sustainable development goals. Peatlands are the most effective terrestrial carbon store on our planet; they function as a buffer for water and compound fluxes, making landscapes resilient to extreme weather and fertilizer scenarios, while simultaneously being an important wildlife habitat. This conference aims to deepen our understanding of the ecosystem functioning and the underlying processes – a major precondition for a sustainable use of wet landscapes.

It is no coincidence that Mecklenburg-Western Pomerania is hosting an international conference on peatlands. Peatlands cover 13% of the land area in this state, making it one of the most peatland-rich states in Germany. So it is appropriate that peatland sciences have become a focal point for education and research in the state. At Greifswald University there’s a full professorship dedicated specifically to Peatland Sciences, the only one of its kind in Germany. Our universities in both Greifswald and Rostock host several strong working groups that contribute to the global scientific community studying peatlands. WETSCAPES – the initiator of this conference – illustrates just how important peatland sciences are for this state and Europe as a whole. Part of the research excellence program of Mecklenburg-Western Pomerania, this interdisciplinary project is funded with 5 million Euros through the European Social Fund. The funding is enabling the consortium to spend just over 4 years investigating the ecosystems of peatlands and coastal sites. Their aim is to develop a scientific basis for the sustainable, conservationary cultivation of peatlands and wet coastal sites, with a particular emphasis on degraded and rewetted areas. They envision a multifunctional future with so-called paludicultures involving rewetted peatlands used agriculturally and peatlands restored primarily for nature conservation purposes.

Mecklenburg-Western Pomerania is proud of its international reputation as a leader in peatland research. The state’s engagement in the field extends to knowledge transfer and implementation of research findings as well. Some 25 years ago our state was the first to implement large-scale peatland rewetting in Germany. In 2012, the first carbon credit from peatland rewetting worldwide was issued here. In 2014, the first paludiculture biomass heating plant started generating heat here. And 2018 saw the the launch of the first company to produce medicine from a plant called sundew, grown on rewetted peatlands in this state. Today, the Greifswald Mire Centre provides an interface for scientists, policy-makers and practitioners, addressing local and global concerns related to peatland. This Centre in Mecklenburg-Western Pomerania pools the capabilities of 50 leading peatland experts from a range of disciplines. Against this background, it is a great pleasure for me to welcome you to this conference under the auspices of the Ministry of Education, Science and Culture of Mecklenburg-Western Pomerania.

Bettina Martin, Minister of Education, Science and Culture, Mecklenburg-Western Pomerania

Bettina Martin,
General information

CONFERENCE VENUE

The conference will take place at the Ulmencampus, Ulmenstraße 69, University of Rostock (see enclosed city map). The presentations will be held in the Audimax and in lecture hall 2 (HS II) within the adjacent Arno-Esch Building. The poster exhibition will take place in the foyers of the Audimax and Arno-Esch-Building on the gallery upstairs.

The Registration and Information Desk can be found in the entrance area of the Audimax.

Opening hours: Sep 10, 08.00 – 19.30
  Sep 11, 08.00 – 09.00
  Sep 12, 08.30 – 18.00
  Sep 13, 08.30 – 16.00

Coffee and lunch will be served in the foyers of the Audimax and Arno-Esch-Building. Drinks and food for the get together / poster session will also be served there.

Throughout the conference, internet access via WLAN will be available using eduroam. If you are unable to use eduroam, you may receive a guest account or you can use the computer pool in room 122 (Haus 3, opposing building). Please contact the assistants at the Registration and Information Desk.

On the upper floor of both conference buildings, there are lockers that can be used for clothes and luggage.

Members of the organizing committee can be identified by their yellow name tags.

PRESENTATIONS

All lecture halls have projectors. Please bring the file with your oral presentation on a usb flash drive to the Registration and Information Desk not later than 60 minutes before your presentation session starts, to transfer it to a local computer. Posters will be presented in the foyers of the two lecture hall buildings on the gallery upstairs. Posters of the topics 1 and 2 will be shown in the Audimax, posters of the topics 3 to 6 will be shown in the Arno-Esch-Building. Please check topic, number and location of your poster at the Registration and Information Desk or with the assistants at the poster exhibition. The posters should be mounted with double-sided tape or pins (available on-site). The 2-minute-presentations and discussions will take place in front of the posters on September 10 from 17.30 to 18.30 as parallel sessions.

EXCURSIONS

Participants who have registered for an excursion are asked to meet at the conference venue in front of Haus 3 (indicated in the enclosed map) until 8.15 on September 11. Each participant will receive a lunch package (incl. drinks). If possible, please wear hiking or rubber boots. Please find the excursion guides in this book from page 166 onwards.

FILM SCREENING “MAGIE DER MOORE”

On Sep 11 at 19.30, the cinema “Lichtspieltheater Wundervoll” will present the nature film “Magie der Moore”. Although the language is German, it will also inspire English-speaking viewers with its spectacular images. Afterwards, there will be a discussion with scientists and citizens on the rewetting of peatlands. The cinema is located in the Friedrichstr. 23, a 15-minute walk away from the conference venue. The entrance fee is € 7.

Film description: Like hardly any other habitat, the moor holds countless stories: Its attraction and dark myths make us tremble and marvel at the splendour of its biodiversity. In MAGIE DER MOORE, the renowned nature filmmaker Jan Haft (“The Green Miracle – Our Forest”) directs our gaze to one of our most important and beautiful biotopes. In the change of the day and seasons, the film shows a place at the transition between water and earth, full of exciting contrasts. In addition to wolves roaming through white tufts of cotton grass, cranes feeding their young in the forest or gracefully dancing adders, we experience carnivorous sundew plants and dainty moss plants whose spores explode in a cracking eruption. A filigree work of art created by nature over thousands of years, which we are only gradually beginning to explore, understand and preserve.

In spectacular pictures, MAGIE DER MOORE presents one of the most famous native habitats. In five years of filming, director Jan Haft created a dazzling kaleidoscope of unique flora and fauna and shows a sensitive ecosystem that needs to be protected. State-of-the-art camera technology was used: slow motion pictures make the fastest movements in the moor visible. Time-lapse images allow the viewer to take a new look at seemingly motionless plants and present the beauty of the moor habitat in fascinating colour changes. Aerial photos show how moors and islands fit into our cultural landscape, and macro photos take a look at the smallest moor dwellers and their exciting stories. In addition, the viewer learns that moors are gigantic CO₂ reservoirs and elementary for our climate.

Narrated by Grimme award winner Axel Milberg, MAGIE DER MOORE is an amazing journey to fascinating life forms that can also be found very close to us.
The conference dinner will take place during a harbour tour with the passenger ship “MS Ostseebad Warnemünde” that will depart on September 12 at 19.30 in Rostock-Warnemünde. Boarding is from 19.00 to 19.20.

The pier of the “MS Ostseebad Warnemünde” is located at the Alter Strom (old stream). You can reach the ship via the local train (S-Bahn) from the station Parkstraße, near the conference venue (direction Warnemünde). You find additional stations near your hotel in the enclosed map. Please use the train tickets in your conference folder (one for arrival and another for departure) and validate it before entering the train by using the electronic machines located on the platform. Get off at the final destination, which is Warnemünde, and follow the guides that will carry a sign “WETSCAPES Conference” or see the route in the enclosed map.

Please note, travel time is about 30 minutes and trains run every 15 minutes. Please wear your name tag. Return of the ship will be at about 22.30. Departure time of local trains back to the city will be 22.29, 22.59 and 23.29.

SPECIAL ISSUE “UNDERSTANDING THE ECOLOGY OF RESTORED FEN PEATLANDS FOR PROTECTION AND SUSTAINABLE USE”

We will publish a special issue of conference papers in cooperation with the open access journal “Soil Systems”. Please follow the link for more information on the special issue or to submit a manuscript: www.mdpi.com/journal/soilsystems/special_issues/WETSCAPES

Deadline for manuscript submissions: 30 September 2019.
**MOORFUTURES – FOR A CLIMATE-FRIENDLY WETSCAPES CONFERENCE**

All participants were offered the possibility to compensate their CO₂ emissions generated by travel, accommodation and event organization. During the conference, you will have the possibility to obtain more information about MoorFutures and to purchase more MoorFutures.

With these voluntary contributions, you invested into the MoorFutures project “Gelliner Bruch”. This fen is located in northeastern Germany and was rewetted in 2017. On the conference website, you will find more information about this rewetting project.

MoorFutures were introduced in Germany as the first carbon credits from peatland rewetting in 2012. MoorFutures have been developed in the federal state of Mecklenburg-Western Pomerania and follow the regional MoorFutures standard. The MoorFutures criteria are clearly defined, scientifically validated, transparent and based on the principles of the Verified Carbon Standard and the Kyoto Protocol. The quality of the MoorFutures credits is guaranteed by the relevant Ministry and related state institutions as well as regional scientific institutions/universities.

**SCIENTIFIC COMMITTEE**

Nicole Wrage-Mönnig, University of Rostock, Chair of Grassland and Fodder Sciences

Bernd Lennartz, University of Rostock, Chair of Soil Physics

Peter Leinweber, University of Rostock, Chair of Soil Science

Gerald Jurasinski, University of Rostock, Chair of Landscape Ecology and Site Evaluation

Ralf Bill, University of Rostock, Chair of Geodesy and Geoinformatic

Hans Joosten, University of Greifswald, Chair of Peatland Studies and Palaeoecology

Tim Urich, University of Greifswald, Chair of Bacterial Physiology

Jürgen Kreyling, University of Greifswald, Chair of Experimental Plant Ecology

Martin Wilmking, University of Greifswald, Chair of Landscape Ecology and Ecosystem Dynamics

**ORGANIZING COMMITTEE**

Gerald Jurasinski, University of Rostock, Chair of Landscape Ecology and Site Evaluation

Peter Leinweber, University of Rostock, Chair of Soil Science

Franziska Schmacka, University of Rostock, Chair of Grassland and Fodder Sciences

Franziska Tanneberger, University of Greifswald, Chair of Peatland Studies and Palaeoecology & Greifswald Mire Centre

Nicole Wrage-Mönnig, University of Rostock, Chair of Grassland and Fodder Sciences
Supporters

We are grateful to the German Research Foundation for funding of the WETSCAPES Conference. The International Union of Soil Sciences supported the attendance of nine students at this conference. The WETSCAPES Conference is part of the WETSCAPES project. We thank the European Social Fund (ESF) and the Ministry of Education, Science and Culture of Mecklenburg-Western Pomerania who funded the project WETSCAPES (ESF/14-BM-A55-0027/16)

Programme Overview

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<td>Joint plenary session “Peatland rewetting, proxies and modeling” (Audimax)</td>
<td>Joint plenary session “Peatland rewetting and vegetation” (Audimax)</td>
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<td>Coffee Break</td>
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<td>Coffee Break</td>
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<tr>
<td>Joint plenary session “Peatland rewetting and water quality II” (Audimax)</td>
<td>Lunch Break</td>
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<tr>
<td>Joint plenary session “Peatland rewetting, land management and policy” &amp; Plenary talk R. Hüttl (Audimax)</td>
<td>Parallel sessions “Greenhouse gas emission &amp; its drivers I” (Audimax) &amp; “Plant growth &amp; decomposition I” (Arno-Esch)</td>
<td>Parallel sessions “Peatland management” (Audimax) &amp; “Element cycling &amp; export” (Arno-Esch) &amp; Wrap up (Audimax)</td>
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<td>EVENING</td>
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<td>Parallel sessions “Mapping peatlands” (Audimax) &amp; “Peatland ecohydrology” (Arno-Esch)</td>
<td>Coffee Break</td>
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<tr>
<td>Poster session &amp; Get together (Foyers)</td>
<td>Public film screening „Magie der Moore” (Friedrichstr. 23)</td>
<td>Conference dinner (Warnemünde)</td>
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Deutsche Forschungsgemeinschaft

German Research Foundation

International Union of Soil Sciences

2015-2024

EUROPÄISCHE UNION
Europäischer Sozialfonds

Europäische Fonds EFFE, ESF und ELEF
in Mecklenburg-Vorpommern 2014-2020
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<td>9.00 -</td>
<td>Greetings (Audimax; Chair: N. Wrage-Mönnig)</td>
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<tr>
<td>9.00 –</td>
<td>W. Schareck (Rector; University of Rostock, Germany)</td>
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<tr>
<td>9.30 –</td>
<td>W. Venohr (Ministry of Education, Science and Culture Mecklenburg-Western Pomerania, Germany)</td>
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<tr>
<td>9.30 –</td>
<td>J. Flasbarth (State Secretary, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany)</td>
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<td>12.00 –</td>
<td>Keynote F. Van Cappellen, University of Waterloo, Canada: Understanding soil organic matter decomposition: back to basics</td>
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<td>12.00 –</td>
<td>Lunch break</td>
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<tr>
<td>13.00 –</td>
<td>Joint plenary session “Peatland rewetting and land management and policy” (Audimax; Chair: H. Joosten &amp; A. Günther)</td>
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<td>13.00 –</td>
<td>Keynote M. Silvius, Global Green Growth Institute (GGGI), Indonesia: Jurisdictional and landscape-wide approach to tropical peatland restoration</td>
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<td>13.30 –</td>
<td>S. Page, University of Leicester, UK: Peatland smallholder agriculture in Indonesia: scenarios for improved land management</td>
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<td>13.45 –</td>
<td>D. Sari, James Cook University, Australia: Landscape audit to reconcile competing claims on the peatlands of Sumatra</td>
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<td>14.00 –</td>
<td>D. Kopansky, UN Environment, Kenya &amp; F. Tanneberger, Greifswald Mire Centre, Germany: The Global Peatlands Initiative</td>
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<td>14.15 –</td>
<td>M. Hohlbein, University of Greifswald, Germany: Next steps to implement paludiculture in Mecklenburg-Western Pomerania</td>
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<td>14.30 –</td>
<td>Plenary talk R. Hüttl, Scientific Director of the German Research Centre for Geosciences (GFZ) in Potsdam, Germany: GFZ wetland research at the Northeastern German Lowland TERENO Observatory</td>
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<td>15.00 –</td>
<td>Keynote R. Artz, Ecological Sciences, The James Hutton Institute, UK: Mapping peatlands remotely – resolution, scale and the quality of ground observations for model training determine the outcome</td>
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<td>15.40 –</td>
<td>T. Morley, National University of Ireland Galway, Ireland: The use of historic surveys for land use change detection and future peatland change calculations</td>
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<td>16.10 –</td>
<td>S. Rannow, Müritz National Park Authority, Germany: Rewilding peatlands in Müritz National Park</td>
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<td>16.25 –</td>
<td>T. Orlov, Sergeev Institute of Environmental Geoscience RAS, Russia: Satellite and airborne monitoring of the rewetting of disturbance peatlands (Orshinsky Mokh case study)</td>
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<td>16.55 –</td>
<td>J. Connolly, Dublin City University, Ireland: Land use on peatlands</td>
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<td>17.15 –</td>
<td>Poster session &amp; Get together with pretzel and beer (Foyers Audimax &amp; Arno-Esch-Building; Chair: N. Wrage-Mönnig &amp; D. Michaelis)</td>
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<td>17.15 –</td>
<td>Film screening “Magie der Moore” (Lichtspieltheater Wundervoll, Friedrichstr. 23, Rostock)</td>
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**September 11, 2019 Field excursions (Meeting point: conference venue, in front of Haus 3, see enclosed map)**

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<td>8.15 – 13.00</td>
<td>Hike through an alder carr</td>
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<td>8.15 – 15.00</td>
<td>Trip to a coastal mire and Baltic Sea beach</td>
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<td>8.15 – 16.15</td>
<td>Historic and recent land use of river valley fens</td>
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<tr>
<td>8.15 – 18.45</td>
<td>Coastal flood mire and research at the Greifswald Mire Centre</td>
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<tr>
<td>19.30 – 21.30</td>
<td>Film screening “Magie der Moore” (Lichtspieltheater Wundervoll, Friedrichstr. 23, Rostock)</td>
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<thead>
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<tr>
<td>9.00</td>
<td>Keynote C. Evans, Environment Centre Wales, UK: Come hell or high water? Mitigation of greenhouse gas emissions from agriculturally drained peatlands</td>
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<td>9.45</td>
<td>M. Kaiser, University of Greifswald, Germany: Mapping greenhouse gas emissions from peatlands using biotope maps and satellite imagery</td>
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<tr>
<td>10.00</td>
<td>B. Lennartz, University of Rostock, Germany: Soil degradation determines hydro-bio-geochemical transformation processes in peatlands</td>
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<tr>
<td>10.15</td>
<td>E. Bijkerk, Trinity College Dublin, Ireland: Understanding calcareous fen ecohydrology for protection and sustainable use</td>
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<td>10.35</td>
<td>Coffee break</td>
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<tr>
<td>11.00</td>
<td>Joint plenary session “Peatland rewetting and microbiota” (Audimax; Chair: T. Uhrich &amp; H. Wang)</td>
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<tr>
<td>11.00</td>
<td>Keynote S. Liebner, German Research Centre for Geosciences (GFZ) in Potsdam, Germany: Microbial response to peatland degradation and rewetting</td>
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<td>11.30</td>
<td>R. Conrad, Max-Planck-Institute for Terrestrial Microbiology, Germany: Pathways of acetate consumption and methanogenesis in Amazonian lake sediments</td>
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<tr>
<td>11.45</td>
<td>H. Wang, University of Greifswald, Germany: Congruent effects of rewetting on pro- and eukaryotic peat communities in formerly drained temperate fens</td>
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<td>12.00</td>
<td>M. Pester, Leibniz Institut DSMZ-German Collection of Microorganisms and Cell Cultures, Germany: Microbial dark matter involved in cryptic sulfur cycling of peatlands and rice paddies</td>
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<td>12.15</td>
<td>E. Verbruggen, University of Antwerp, The Netherlands: Microbiome recovery in rewetted fens</td>
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<td>12.35</td>
<td>Lunch break</td>
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<tr>
<td>13.35</td>
<td>Parallel session “Greenhouse gas emission &amp; its drivers I” (Audimax; Chair: N. Wrage-Mönnig &amp; F. Koebsch)</td>
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<tr>
<td>13.35</td>
<td>Keynote M. Strack, University of Waterloo, Canada: Peatland restoration in Canada – Returning carbon sink function</td>
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<td>14.05</td>
<td>B. Tiemeyer, Thünen Institute of Climate-Smart Agriculture, Germany: Carbon and greenhouse gas balance of a black alder (Alnus glutinosa) ecosystem on organic soils</td>
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<tr>
<td>14.20</td>
<td>D. Kühn, University of Rostock, Germany: Carbon dioxide and methane exchange of soils, trees and ditches in drained and rewetted fens</td>
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<tr>
<td>14.35</td>
<td>M. Weil, University of Greifswald, Germany: Seasonal dynamics of methane emitting microbiomes in drained and re-wetted fens of Northern Germany</td>
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<td>14.50</td>
<td>M. Davey, Norwegian Institute of Bioeconomy Research, Norway: Methane production in Central European fens is linked to edaphic properties, not large-scale climatic gradients</td>
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<td>15.10</td>
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<td>15.35</td>
<td>Parallel session “Greenhouse gas emission &amp; its drivers II” (Audimax; Chair: N. Wrage-Mönnig &amp; F. Koebsch)</td>
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<td>15.35</td>
<td>P. Mathijssen, University of Münster, Germany: Effects of carbon exchange uncertainties in estimating peatland radiative forcing over the Holocene</td>
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<td>15.50</td>
<td>C. Gutekunst, University of Rostock, Germany: The effect of topsoil removal and Spirogyra spreading on the net greenhouse gas balance of a rewetted peat bog</td>
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<td>16.05</td>
<td>S. Paul, University of Basel, Switzerland: Do cover fills reduce peat oxidation and carbon emissions from managed organic soils?</td>
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<td>16.20</td>
<td>A.-H. Purre, Tallinn University, Estonia: Spatial and interannual variations of CO2 exchange on rewetted milled peatlands</td>
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<td>16.35</td>
<td>W. Horwath, University of California, United States: Restoring degraded peatlands with rice cultivation: Evaluating greenhouse gases and soil C dynamics</td>
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<td>16.50</td>
<td>B. Poereid, Norwegian Institute of Bioeconomy Research, Norway: Modelling carbon cycling in wetlands</td>
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<td>17.10</td>
<td>Conference dinner during a harbour tour (Rostock-Warnemünde)</td>
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<tr>
<td>Time</td>
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<tr>
<td>09.00 – 10.30</td>
<td>Joint plenary session “Peatland rewetting and vegetation” (Audimax; Chair: M. Wilmking &amp; A. Anadon-Rosell)</td>
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<td>09.00 – 10.30</td>
<td>Joint plenary session “Peatland rewetting and greenhouse gas emissions” (Audimax; Chair: G. Jurasinski &amp; F. Tanneberger)</td>
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<td>09.45 – 10.15</td>
<td>Parallel session “Peatland management” (Audimax; Chair: J. Kaduk &amp; B. Tiemeyer)</td>
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<td>11.00 – 11.30</td>
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<td>Parallel session “Peatland management” (Audimax; Chair: J. Kaduk &amp; B. Tiemeyer)</td>
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*At the end of each session, 5 minutes are scheduled for summarizing key messages.
Peatland rewetting and water quality
The influence of salt water on the composition and molecular structure of peat-derived dissolved organic matter

Dissolved organic matter (DOM) plays a key role in many biogeochemical processes in peatland ecosystems, such as the formation of greenhouse gases and dynamics of plant nutrients. As sea levels are expected to rise due to global change, saltwater intrusions into coastal peatlands become more likely. To understand changes in the ecosystem that are caused by saltwater intrusions, it is essential to study the effects of salt on the composition and molecular structure of the peatland DOM. In this study, DOM from different peat samples was extracted with fresh- and saltwater. Various mass spectrometrical (Py-FIMS, FT-ICR-MS), chromatographical (GC-MS, HPLC) and spectroscopical (S, N-XANES, ICP-OES) methods were used to examine molecular differences in these DOM extracts. First results show a coagulation of large molecules and an overall removal of DOM. Nevertheless, a release of certain microbially easily degradable molecule classes (e.g., carbohydrates, peptides and free fatty acids) was observed. Furthermore, the data indicates a release of ammonium along with a drop in pH, probably due to cation exchange on particles and the peat surface. This nutrient release can be expected to affect microbial and plant communities. Smallest differences in DOM composition between fresh- and saltwater extracts were found in highly decomposed peats. This suggests that protection from saltwater intrusions should be preferentially focussed on less degraded, rather than highly decomposed peatlands.

Unravelling the importance of polyphenols in rewetted riparian peatlands

There are major attempts to rewet peatlands in Europe and other parts of the world to restore their unique biodiversity and their important function as nutrient and carbon sinks. However, elevated concentrations of dissolved organic carbon, ammonium and phosphate have been measured in the soil porewater of the upper degraded peat layers of rewetted riparian peatlands at levels of one to three orders higher than the values in pristine systems. Additionally, the increased consumption of electron acceptors implied increased microbial activity in the degraded topsoil of rewetted peatlands. In this context, it was still questionable if long-term mineralization over the decades of drainage and intense agricultural use caused an enrichment or a substantial decline of enzyme-inhibiting polyphenols. Therefore, substrate samples were taken from the upper 20 cm soil layer and fresh roots of dominating vascular plants and mosses (i.e., the peat parent material) of five degraded and six near-natural ground-water fed peatland sites. We determined total phenolic contents in these samples, and quantified hydrolysable and condensed tannic substances. Polyphenolics from less decomposed peat and living roots served as an internal standard for polyphenol analysis and for enzyme inhibition tests. As hypothesized, we found that highly degraded peat contained eight times lower levels of total polyphenolics and 50 times lower levels of condensed tannins than less decomposed peat. In addition, we found that polyphenol contents of plant tissue were strongly different among plant species, with highest contents in roots of Carex appropinquata that were more than 10-fold higher than Sphagnum spp. (450 vs. 39 mg/g dry mass). Despite large differences between natural and rewetted sites, enzyme activities and peat degradation were not significantly correlated, indicating no simple linear relationship between polyphenolic contents and microbial activity.
The importance of water quality in *Sphagnum* farming on rewetted peatlands

*Sphagnum* farming is paludiculture on rewetted degraded peatlands. Harvested *Sphagnum* biomass can be used as a renewable raw material for horticultural substrates, substituting fossil peat. *Sphagnum* mosses require adequate water quantity, water quality and nutrient stoichiometry to proliferate. In this study, we investigate nutrient dynamics and *Sphagnum* performance in the peatland Hankhauser Moor (NW-Germany). The site was developed on former bog grassland in 2011 (4 ha) and expanded in 2016 (+10 ha). It comprises *Sphagnum* production fields surrounded by narrow ditches and bunds used as causeways. To convert the bog grassland into a *Sphagnum* farm, the sod was removed and *Sphagnum* fragments were spread on the peat surface. The site has been rewetted and the water table is regulated with an automatic ditch irrigation system connected to an adjacent stream.

Our results show that these ditches successfully irrigate the *Sphagnum* lawn over the entire production field of 10 m width and thus directly affect biomass production via water quantity and quality. *Sphagnum* covers the lawn homogeneously throughout the fields and is able to alter the pH of its environment regardless of slightly alkaline ditch water. The infiltrating irrigation water is a substantial source of potassium and particularly phosphorus. While large amounts of nitrogen are supplied by atmospheric deposition (ca. 22 kg N ha$^{-1}$ a$^{-1}$) mainly from agricultural surroundings, its concentration is low in pore water in the lawns and in the ditch water. An ammonium legacy persists in deeper peat layers of the 2016 site, but concentrations have decreased substantially within a year. Despite high N deposition, we observed a high *Sphagnum* biomass productivity, which likely results from a balanced nutrient stoichiometry. Our study over six years shows that successful *Sphagnum* farming can be persistently accomplished on former agricultural peatlands using a surface water-fed irrigation system under nutrient-rich conditions.

Rewetting agriculturally used peat soils: biogeochemistry, management dilemmas and solutions

Rewetting of degraded peatlands will strongly affect sulphur (S), iron (Fe), nitrogen and phosphorus (P) cycling, which can result in a strong eutrophication of rewetted peatlands. The degree of phosphate saturation (DPS) appears to be a very good predictor for the degree of P mobilization after rewetting. For most formerly drained agriculturally used peatlands, P mobilization after rewetting is too high to allow the development of a species rich peatland. Furthermore, although high groundwater levels can strongly decrease land subsidence, emissions of carbon dioxide and methane emissions can, at least temporarily, strongly increase due the high availability of easily degradable organic matter in the degraded peat layer. Topsoil removal will directly enhance the restoration of permanent high groundwater levels. The resulting anaerobic conditions in combination with a low P availability strongly decreases decomposition and nutrient mineralisation rates and allows the development of a biodiverse peat forming vegetation. The removed, nutrient-rich, highly degraded topsoil could subsequently be used to level up drained, subsiding peatlands that are still in agricultural use. This will allow the establishment of higher groundwater levels in restored peatlands without increasing flooding risks of the surrounding agricultural area.

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Growing *Sphagnum* lawns provide numerous products and services like fibre production for growing substrates; CO$_2$-sequestration at low CH$_4$ emissions; nutrient sequestration and habitat. *Sphagnum* growth is favoured by water levels 2–10 cm below the surface. Water available for irrigation is, however, often suboptimal or even toxic for *Sphagna* (e.g. high pH, mineral and/or nutrient content). We investigate in field and lab trials how water quality controls *Sphagnum* moss performance in rewetted bogs and fens.

Under controlled conditions, high alkalinity (> 0.8 meq l$^{-1}$) and the presence of bicarbonate ions effectively halted *Sphagnum* moss growth. High alkalinity caused irreversible physiological damage within 1–3 weeks depending on bicarbonate levels and species. In general, *Sphagnum* lawn development was highest where incoming water was weakly buffered or sufficiently acidified by *Sphagnum* biomass. Interestingly, *Sphagnum* species exposed to high calcium/sodium levels differed little from controls but largely lowered pH values. Calcium absorption and uptake may play an important role in lowering the alkalinity and consequently pH of buffered water within days.

In field trials, accumulation of minerals showed little adverse effects. In contrast, at increased nutrient loads, vascular plants slow down *Sphagnum* growth by shading, more so where high (atmospheric) nitrogen imposes stress on *Sphagnum*. Sufficient potassium and phosphorus in irrigation water can alleviate nitrogen stress.

Sufficient water is a key factor promoting robust *Sphagnum* lawn development even on fen peats. Flooding with alkaline water is, however, toxic to *Sphagnum* within days. Physiological response to high pH and high alkalinity/bicarbonate showed to be species-specific.

*Sphagnum* moss restoration and paludiculture *Sphagnum* farming should focus on sufficient water supply without flooding, target robust species and reduce stress imposed by nitrogen loads and high alkalinity.
Peatland rewetting, land management and policy
Jurisdictional and landscape-wide approach to tropical peatland restoration

In 2018, the provincial government of Central Kalimantan requested support for the development of a jurisdictional program to enable and finance the rewetting, revegetation and revitalisation of more than 2 million ha of peatlands. A province-wide approach is warranted, first, because it will help make site-based peatland restoration efforts in individual landscapes legally and financially secure, thus encouraging more and longer-term private and public investment. Second, it will ensure the coordination of all mitigation actions in the province and alignment with government systems and priorities, including Indonesia’s peatland policies, the NDC and Indonesia’s policy of fire prevention. The program will coordinate and ‘bundle’ the management and financing of various peatland landscapes, enabling development of larger bankable projects on common designs for various management options, with a focus on livelihood improvements linked to a variety of business models in and around peatlands, such as paludiculture. At the provincial level, the program will support mechanisms for de-risking and financing projects through blended finance and micro-finance, and it will strengthen policy, governance and institutions, MRV and knowledge management. Primary benefits will accrue to the people of Central Kalimantan and those in neighbouring provinces and countries, in the form of reduced CO2 emissions, reduced risks of peat fires and associated haze — linked to billions of dollars in economic damages — together with improvements in water quality and human health, productivity of farms, forests, and fisheries, and avoidance of land subsidence and flooding caused by the degradation of peatlands. The project will create a conducive enabling environment, offer supporting services, and ensure that basic standards can be met. It is not meant to force all projects into a single mould, but will rather encourage creativity, innovation, and local enterprise.

Peatland smallholder agriculture in Indonesia: scenarios for improved land management

Although tropical peatlands are considered ‘marginal to poor’ for agricultural production, 5–7 million ha in SE Asia have been cleared and drained to enable production of plantation and food crops. Adverse environmental impacts associated with this land use change include increased greenhouse gas emissions, soil degradation and fire, which have negative influences on global climate, food production, livelihoods and health. In terms of peat oxidation, emissions of 64 Mt C a\(^{-1}\) are attributable to large-scale plantations, but a sizable 49 Mt C a\(^{-1}\) can be ascribed to smallholder agriculture (SHA). Within Indonesian peatland SHA communities, undesirable environmental impacts are exacerbated by inefficient markets, unsustainable production systems, land alienation and the absence of access to alternative food systems and income sources. It has been argued that these factors drive SHA farmers to adopt short-term, environmentally and/or socially sub-optimal strategies to secure livelihoods. However, while this complex situation has gained limited international attention, e.g. linked to peatland fires and plantation expansion, there remain important gaps in our understanding of the functioning of the smallholder landscapes as linked socio-ecological systems. We contend these must be addressed through a multidisciplinary approach. Such approaches must incorporate an understanding of the environmental impacts of current SHA practices on peat soils, and detailed analysis of the livelihood practices of smallholders. Such an approach can assist in developing a more accurate picture and provide a basis for new approaches to SHA land management to reduce environmental impacts, e.g. by implementing viable alternatives to drainage-based agriculture, while recognizing the need for co-produced solutions that are credible and that take account of farmers’ livelihood needs, understandings and aspirations.
Landscape audit to reconcile competing claims on the peatlands of Sumatra

Formal methods for assessing the effectiveness and the economy of a land allocation policy do not yet exist. The complexity of multi-sector arrangements that pertain in lands has hindered the development of suitable metrics. In Indonesia, the absence of effectiveness analysis for policy-making has resulted in continuing conflicts among stakeholders: government, business, NGOs, and local communities.

We propose an audit at a landscape scale as a way of controlling the complexity. We test this idea with an experimental audit on Kampar Peninsula, a peat landscape in Pelalawan district, Riau.

Conflicts among stakeholders in Kampar have occurred since exploitation of the peatland began in the 1990s. The disputes escalated following the implementation of a new peatland restoration regulation. The series of peat protection and restoration measures include the delineation of protection zones and the land swaps of any overlapping land allocations to other locations. There have been intense controversies among stakeholders over the implementation of this new policy.

We conducted a performance audit on the effectiveness and the economy of the new peatland regulation. We applied commonly accepted performance auditing standards to generate criteria of effective peatland zoning. Radar and Landsat imagery were utilised to map the existing land uses and to delineate different spatial allocations of all land users. We produced maps showing three scenarios of spatial plans that would reconcile competing land claims. We also calculated the costs of land swaps for each scenario. We argue that this new delineation would be more effective and more economic in resolving spatial conflict.

This landscape audit method will have wide potential application for auditing best practice and will have immediate application for resolving the current governance failures on the Kampar Peninsular.

The Global Peatlands Initiative (GPI) is an effort by leading experts and institutions to save peatlands as the world’s largest terrestrial organic carbon stock and to prevent it being emitted into the atmosphere. Partners to the Initiative work together to improve the conservation, restoration and sustainable management of peatlands. In this way, the Initiative will contribute to several Sustainable Development Goals, including reducing greenhouse gas emissions, maintaining ecosystem services and securing lives and livelihoods through improved adaptive capacity. Focal countries are the Republic of Indonesia, Peru, Republic of Congo and the Democratic Republic of Congo. In 2017, a rapid assessment looking at peatland location and extent, threats affecting peatlands, policies and instruments has been published by the GPI partnership. Currently, an updated global assessment of the status of peatlands and their importance in the global carbon cycle is being prepared.
Next steps to implement paludiculture in Mecklenburg-Western Pomerania

About 13% of the federal state Mecklenburg-Western Pomerania (Northeast-Germany) are covered by peatlands. Drained peatlands (mainly for agriculture) cause about 30% of the greenhouse gas emissions of the federal state. In order to reach the goals of the Paris Agreement, rewetting of peatlands is inevitable. A transition to paludiculture (productive use of wet peatlands) can save emissions while maintaining productive use. However, paludiculture is hardly an option for most farmers so far.

A synthesis of recent projects of the Greifswald Mire Center (GMC) shows tasks and methods for the next steps to implement paludiculture in Mecklenburg-Western Pomerania. The suitability of peatland areas for paludiculture was identified based on current agricultural use and existing legal restraints (mainly conservation law). The potential of two different kinds of paludiculture were described – “permanent-grassland paludicultures” and “crop-paludicultures”. In preparing implementation (through pilot projects), the potential of sites was elaborated in a first step by additional GIS-analyses and interviews with land-users and stakeholders. In a second step, the economic and legal situations were considered and technical planning commissioned. During this process, a number of hurdles were identified, like the non-eligibility of wetland-adapted crops for agricultural payments in the Common Agricultural Policy, a lack of adapted financial instruments and deficiencies in exploitation chains as well as in acceptance of rewetting and in cooperation between authorities. Demonstration sites are urgently needed to test management of paludiculture-plants in practice and to show the feasibility of paludiculture in order to convince and mobilise stakeholders.

Implementation of paludiculture needs efforts on different levels. The described projects of the GMC strive for prompt, yet individual solutions for demonstration sites, which are key to large-scale implementation.

GFZ wetland research at the Northeastern German Lowland TERENO Observatory

Wetlands are unique in their biodiversity and ecosystem services, and play a crucial role in the global carbon cycle. Under pristine conditions, wetlands constitute a natural carbon sink and store almost as much carbon as is contained in the global vegetation. However, it is estimated that 64% of wetlands were lost since 1900 AD due to human management. Much of the degraded wetland area is now a significant and long-term greenhouse gas (GHG) source contributing about 5% of the global anthropogenic CO₂ emissions. Mecklenburg-Western Pomerania is the federal state of Germany with the highest proportion of peatlands (13% of the land area), a special type of wetlands. About 20 – 30% of the statewide CO₂ equivalent emissions are attributed to drained peatlands. Over the last three decades, about 25,000 hectares of these peatlands were rewetted with the aim to mitigate their GHG emissions and to restore their natural carbon sink capacity. However, many rewetted peatlands remain net GHG sources even more than a decade after rewetting, and substantial uncertainty remains with regard to if and when these ecosystems turn into carbon sinks again.

The Helmholtz Northeastern German Lowland Observatory (TERENO-NE) lead by the GFZ German Research Centre for Geosciences provides an excellent infrastructure and scientific platform for a systematic and comprehensive assessment of the success of rewetting projects in Northeast Germany. This plenary talk will present major achievements of GFZ wetland research conducted as part of TERENO-NE in collaboration with the University of Rostock and further institutions. It will exemplify outcomes of long-term dynamics and drivers of net GHG exchange from the coastal brackish peatland ‘Hütelmoor’ and the freshwater riparian peatland ‘Polder Zarnekow’ retrieved through time series data from micrometeorological eddy-covariance measurements and molecular microbial and geochemical surveys. Moreover, emerging transregional synergies between TERENO-NE and the Mecklenburg-Western Pomerania research program ‘WETSCAPES’ will be outlined including the discussion of potentially new monitoring sites, joint approaches and future scientific directions.

Plenary talk: Reinhard Hüttl, Scientific Director of the German Research Centre for Geosciences (GFZ) in Potsdam, Germany
3
Mapping peatlands
The use of historic surveys for land use change detection and future peatland change calculations

Irish peatlands have undergone substantial land use change and degradation leading to a highly modified landscape with varied land cover and thus restoration potential. Recent cessations in extractive practices within peatlands have created a need to evaluate the suitability of future peatland restoration at landscape scales. However, we lack a detailed benchmark assessment of peatland extent to assist in these efforts. To fill this void, we digitized and geo-rectified high-resolution historical maps (The Commissioners Report on the Nature and Extent of Bogs in Ireland [1810–1814]) to assess their utility to form a baseline from which we can assess ecosystem change. We contrasted the maps with up-to-date higher resolution satellite data (e.g., Sentinel-2) to detect land use change on peatlands. We found the historical maps to be extremely accurate with low Residual Mean Square Error (RSME) suitable for individual peatland land use change detection. This has allowed us to develop a much more accurate quantification of GHG fluxes for peatlands that have undergone land use change. These findings have implications for the recent EU amendment to the 2030 Climate and Energy Framework that now must account for emissions and removals of GHGs from wetlands (peatlands).

Mapping and monitoring peatlands can be extremely challenging. On the one hand, the slow growth rates of many key peatland vegetation species produces relatively little difference in signal between seasons. On the other, the repeat mosaic patterning of some types of peatlands can require high-resolution imagery. Damage to peatlands is often hard to observe, unless it has resulted in wholesale change of the surface cover. For example, drainage ditches can be as narrow as 50 cm, below the resolution of freely available satellite data, and can be hard to detect even on high-resolution aerial photography. Peatlands can be relatively small but frequently occurring features in the landscape that are hard to map and monitor at the appropriate scale. In other cases, the challenge is monitoring conditions across large areas and major altitude gradients. I will show some examples ranging from national scale to site-level mapping and monitoring. High quality ground observations are key to successful remote assessments.

Mapping peatlands remotely – resolution, scale and the quality of ground observations for model training determine the outcome

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Rebekka Artz
Ecological Sciences, The James Hutton Institute

Terry Morley
1
National University of Ireland Galway

John Connolly
2
Dublin City University

Juliana Adelman

Rewilding peatlands in Müritz National Park

In the last three decades, Müritz National Park authority has restored 2,210 ha of peatlands. More than 100 projects have been implemented, ranging from closing ditches affecting only few square meters of peatland to EU-LIFE Projects covering more than 1,000 ha.

The restoration of the natural water regime is a main mission defined in the National Park law. It is essential for restoring and conserving habitat functions as well as wilderness areas. One of the first peatland restoration projects started in 1994 and aimed at rewetting a wilderness area of 1,720 ha. The area is located at the eastern shore of lake Müritz. Since 1998, it is dedicated as a wildlife sanctuary where hunting is strictly prohibited.

A synoptic analysis reviews the available information regarding vegetation changes in the area from 1991 to 2012. Additionally, remote sensing data helped to identify changes in forest cover. A combination of spectral information and laser scanning data was used for a detection of changes in vertical structure. Vegetation cover above 2 m was identified. This data were essential to detect vegetation changes of forest cover and open ground habitats. The data gives a detailed spatial as well as temporal picture of the changes in the wilderness area. The analyses document the effective renaturation of peatlands in the area. An increase of water table by 20 cm resulted in retreat of forest cover and an increase of reed and native fen flora. Red deer and wild boar had a decisive impact on the changes. They helped to increase biotope diversity and the spread of rare habitats protected under the Flora-Fauna-Habitat Framework.

Satellite and airborne monitoring of the rewetting of disturbance peatlands (Orshinsky Mokh case study)

Peatlands disturbed by drainage and peat extraction occupy large areas in Russia. These disturbed systems are a source of significant adverse environmental impacts, including greenhouse gas emissions and fires. There are some rewetting projects, some of which cover very large areas. The implementation of projects takes considerable time. Moreover, the inaccessibility of the rewetted areas forces us to look for remote sensing monitoring methods. Orshinsky Mokh, an extensive cutover raised bog remnant is located in the Tver region. Rewetting of about 5,400 ha started in 2014. Medium resolution satellite images were chosen as a basis. For the period 1969 – 1975, we used images of Corona (2 m/px); for the period 1985 – 2003 Landsat 4, 5, 7 (30 m/px); for the period 2003 – 2013 – Landsat 5 (30 m/px); for the period 2013 – 2015 – Landsat 8 (30 m/px); for the period 2015 – 2018 – Landsat 8 and Sentinel 2 (10 m/px). The rewetting period could be monitored once every two weeks. Automated handling allows us to process new incoming images in near real-time. We chose four key sites within the rewetted area in which we used drone imaging and mapping. The drone images allowed us to verify satellite monitoring results and to implement detailed monitoring for the key sites. The main surface cover types in the satellite monitoring are open water (NDVI index), bare peat, and 8 – 12 classes of plant communities. Processing of image time series is used for quick identification of expanding and new open water areas and of vegetation expanding over the bare peat. The monitoring results show that the area of bare peat decreased by 1 – 2 % (of the total rewetted area), and the area of open water and areas covered with moisture-loving vegetation increased by 4 – 5 % since 2014.
Globally, peatlands play a role in the regulation of the climate. When peatlands are in a pristine condition, they sequester CO$_2$ from the atmosphere and store it as carbon. However, peatlands have been under severe strain for decades. Irish peatlands cover about 20.6% of the land and up to 85% are degraded. Degraded peatlands are a source of greenhouse gas. EU member states must quantify greenhouse gas emissions and removals from wetlands. Land use and land use change on peatlands has implications for the amount of greenhouse gases that are emitted or sequestered. Medium resolution satellite data were analysed using a combination of object-based image assessment and peatland maps to produce an Irish peatland land use map. Four peatland land use types were mapped: grassland, forestry, industrial peat production and residual peat. Persistent cloud cover was an issue along the western seaboard and peatlands in these areas were excluded from the analysis. Despite this issue, the results show that, at coarse scales, 66% of peatlands have undergone land use change: 35% to grassland; 27% to forestry and 4% to industrial. The overall map accuracy was 77%.
4 Peatland ecohydrology
Impacts of the water table elevation on water balance components of peatlands

Large areas of the northern German Lowlands are characterized by shallow water tables and often these areas are drained peatlands. The drained peatlands are responsible for a large part of the anthropogenic CO₂ emissions of the agricultural sector in Germany. Stopping of drainage and increasing of the water tables at these sites is seen as a possibility to reduce the greenhouse gas emissions. But the increase of the water tables on peatland sites needs additional water supply from the catchment and is related with impacts on other water balance components of the peatland sites as well as effects on the water balance of the whole water basin. Therefore, conflicts between different interest groups regarding the target water levels in regions with restored peatlands occur frequently. A good knowledge of the impacts of a water table elevation on water balance components is a precondition for the development of successful rewetting measures and prevention of conflicts.

A lysimeter station located at a grassland site within the Spreewald wetland in North-Eastern Germany was used to analyse the impact of increased target water levels in early spring on the development of the water budget components. The results attest that rising water tables caused increasing evapotranspiration if the vegetation is adapted to these conditions. This adaptation may take place within a few years of elevated water tables. High water tables in spring do increase the subsurface water storage. However, this can compensate for the increased evapotranspiration only for a few weeks and not for the entire season. The varying meteorological conditions of the investigation period and especially periods with extreme precipitation had a much greater effect on the water budget than raising target water levels in spring. In the long term, higher water tables lead to a change in the vegetation composition, being the main reason for increasing evapotranspiration values.

Restoring human-induced alternative stable states in rewetted bog remnants

Peatland overexploitation resulted in heavily altered landscapes with detrimental effects on hydrology, water quality and climate. To counteract these negative ecological effects and to improve ecosystem functioning, peatland restoration focused on rewetting bog remnants. Bog rewetting resulted in more stable and higher groundwater levels, but it also created deeply inundated lagoons due to peat elevation heterogeneity created by former land use. Terrestrialization of these large water bodies is often hampered, because carbon and light limitation, and wind-driven waves create an unsuitable habitat for peat-forming mosses. The long-term transition towards characteristic bog vegetation is impeded, creating detrimental alternative stable states, namely open water versus peat-forming peatmoss vegetation, in rewetted bog remnants.

Instead of performing complex and expensive hydrological measures to locally improve the hydrology of deeply inundated lagoons, we propose and investigate a novel restoration concept in which we use temporarily floating habitat structures to overcome peatmoss establishment thresholds. We tested whether newly developed potato waste-derived BESE-elements®, floating just below the water surface or behind wave-breakers can ameliorate carbon and light limitation allowing peatmosses (S. cuspidatum or S. palustre) to thrive inside. Our experiment revealed that by transplanting peatmosses in BESE-elements®, floating just below the water surface or behind wave-breakers, we can ameliorate carbon and light limitation allowing peatmosses (S. cuspidatum or S. palustre) to thrive inside. Our experiment revealed that by transplanting peatmosses in BESE-elements®, the biomass of S. cuspidatum and S. palustre was strongly increased, and that accompanying bog vegetation developed on the floating raft by providing physical structure, and by overcoming light and carbon limitation. We conclude that we are able to, artificially, induce a state shift from open water to peat-forming peatmoss vegetation using temporary establishment structures without large-scale and expensive hydrological measures.
Hydrogeochemical reactivity of the peatland soils

Peatlands are a valuable but environmentally vulnerable resource. They represent a globally-significant carbon and energy reservoir and play major roles in global water, nutrient and biogeochemical cycles. Peat soils (i.e., peat) are highly complex porous media with unique physical and hydraulic properties; where significant, and only partially reversible, shrinkage occurs during dewatering (including water table fluctuations), compression and/or decomposition. This complex nature of peat properties controls water flow, which in turn affects reactive and non-reactive solute transport and biogeochemical functions. For instance, the change in peat properties during wetting and drying influences the heterogeneous distributions of microbial habitats and activity in peat soil and plays a crucial role in emission of greenhouse gases in peatlands. This complex hydro(bio)geochemical reactivity of the peatland soils highlights the future research focus on multi-scale studies that integrate the acquisition of physical, hydraulic, chemical and microbial data in the laboratory, with field-based information on hydrology, porewater geochemistry, microbial diversity and functions, and biogeochemical rates and fluxes. In this presentation, we present the current knowledge of hydro-physical properties of globally available peat soils and discuss the implications for biogeochemical processes.

Advances in hydrological modelling of drained and cultivated fen soils

Knowledge of hydrological dynamics in drained and cultivated fen soil profiles is essential for a precise calculation of greenhouse gas emissions. Until now, several estimation procedures exist, basically depending on site-specific conditions like land-use, vegetation, water table and fen soil type. To some extent, these approaches are vulnerable to under- and overestimation of local greenhouse gas emissions by neglecting heterogeneous properties along fen soil profiles potentially differing from horizon to horizon. Hydrological modelling of water dynamics in fen soils characterised by a progressed moorsh-forming process is restricted due to a lack of valid parameters describing available water retention functions. In the present study, a general applicable parameter set to solve the van Genuchten-Mualem water retention equation for fen soil horizons formed by drainage and cultivation has been developed based on a comprehensive dataset consisting of 405 horizontal data from fen soil profiles sampled at altogether 15 peatland areas in Germany. Different categorizations of the data were checked to account for various states of peat decomposition and to reduce the range of measured volumetric soil water contents at specific pressure heads. Finally, bulk density was used as a cluster variable to consider the intensity of the moorsh-forming process within every horizon category. Subsequent parameter estimation was conducted by the RETC programme and validation of the estimated parameters was realized for in total four monitoring plots varying in land-use type, climate and fen soil profile, by modelling water dynamics using HYDRUS-1d.
Redox potential in drained and undrained mesotrophic fen

Reduction-oxidation (redox) reactions are central to the adsorption and release of carbon and nutrients in all soils. Different electron acceptors are used by microbes to gain energy according to their availability and ease of use. The presence and status of different electron acceptors and donors affects the availability of electrons in the soil. The redox conditions in soils can be described by the electric potential compared to a standard hydrogen electrode.

Recent developments in measurement methods have enabled continuous field measurements of redox potential. As redox reactions are key to carbon dioxide and methane emissions and the release of phosphorus and dissolved organic carbon from peat soils, the redox state of peatlands could be used to improve models that predict the functioning of these ecosystems under different water table regimes.

We present results from a redox measurement campaign of two years at the Lakkasuo mire in southern Finland. The measurements were conducted at a mesotrophic site with three different drainage regimes: pristine, short-term drainage and long-term drainage. At the site, also WTL, rainfall, air and soil temperature and other environmental variables are measured.

Initial analysis shows that short- and long-term drainage results in a more stable redox regime in the surface layer (5 cm depth) and that long-term drainage results in a higher redox potential at 15 cm depth. In the pristine state, conditions are highly reducing most of the time already at 15 cm depth.
Peatland rewetting, proxies and modelling
Come hell or high water? Mitigation of greenhouse gas emissions from agriculturally drained peatlands

Agriculturally-drained peatlands account for ~2.5% of global CO₂ emissions, and ~20% of CO₂ emissions from agriculture and land-use. Agricultural drainage causes peat compaction, subsidence, increasing requirements for energy-intensive pumped drainage, and ultimately land degradation or abandonment. With growing recognition of these environmental costs, efforts are being made to re-wet former agricultural peatlands. In the UK, upland bogs that were ditched to support grazing in the 20th century are now being re-wetted. In the lowlands, however, most organic soils remain drained. Fully re-wetting this highly productive land would have major economic and societal impacts, and risk exporting emissions from food production to other countries. In SE Asia, socio-economic challenges are even more acute, with plantation agriculture on coastal peat supporting the livelihoods of millions of people. Consequently, any plan to reduce agricultural peatland emissions needs to either maintain existing income, or develop alternative income streams. Efforts are now being made to develop high water table (paludiculture) alternatives to drainage-based agriculture, but these cannot yet be implemented commercially at scale. Despite the urgent need to achieve ‘net zero’ emissions under the Paris Agreement, it seems likely that many peatlands will remain under conventional agriculture for the foreseeable future, making it essential that measures are developed, tested and implemented to reduce emissions from these areas. This presentation will evaluate the extent to which peatland emissions can be mitigated by changes in agricultural management, based on data from the UK, SE Asia and elsewhere. It will consider the challenges, opportunities, trade-offs and co-benefits of emissions mitigation, including impacts on subsidence, drainability and agricultural lifetime. Based on a synthesis of flux measurement data, the potential to mitigate global emissions by raising water levels in agricultural peatlands will be shown to be significant. The presentation will also consider the challenges for capturing mitigation measures in national emissions inventories, and opportunities for improved monitoring by Earth Observation data.

Mapping greenhouse gas emissions from peatlands using biotope maps and satellite imagery

Vegetation is well suited as a proxy to assess greenhouse gas (GHG) fluxes from peatlands. Plants provide substrate, can indicate water tables and other site conditions, and can act as a conduit for gases. Yet, mapping vegetation over large areas is time consuming. It would therefore be opportune to use pre-existing vegetation data, like those provided by German biotope maps, or to use remote sensing (RS) for assessing GHG fluxes. We translated existing ‘Greenhouse gas Emission Site Types’ (GESTs) to biotopes mapped in the Peene Valley in NE Germany. The biotope map was also used as a ground reference for a supervised classification of multispectral satellite RS data. Classification used a random forest algorithm and a stack of RapidEye scenes with nine different time stamps. Training areas for RS could be delineated for only 18 biotope types of sufficient size and purity. Biotope types of open water (n=2) and with woody vegetation (tree-dominated: n=6, shrubs: n=2) could not be distinguished individually and were lumped. For the resulting 11 classes, an overall accuracy of >90% was reached. Subsequently, GHG emissions were calculated using both approaches. Emission values could be assigned to all 55 biotope types on peat soil. The 11 RS classes were assigned the GEST value of the respective associated biotope types; values were averaged for the open water and wooded classes. Based on biotope maps, the total emissions from the 1,231 ha large study area were 11,549 t CO₂e a⁻¹; and 10,166 t CO₂e a⁻¹ based on RS data. The difference between the two approaches is less than 15%. The use of biotope maps as ground reference for RS is not ideal, as many biotope units are mosaics of smaller patches. The accuracy reached for the 18 biotope types used in training is encouraging. Both methods seem principally suited to assess GHG emissions without obtaining new field data. Whereas the direct approach via biotope maps is faster, RS could provide additional information on the vegetation mosaics.
Soil degradation determines hydro-biogeochemical transformation processes in peatlands

Peatlands are well known for their global significance as a long-term carbon sink as well as a source for greenhouse gases and water-bound substances depending on water management and soil degradation. We have assembled a comprehensive data set covering entire Europe and Canada aiming at deriving general functions of hydro-biogeochemical transformation and state of peat degradation. The results show that the hydraulic parameters of peat soils vary over a wide range confirming the pronounced diversity of peat. Peat decomposition significantly modifies all hydraulic parameters. A bulk density of approximately 0.2 g cm$^{-3}$ was identified as a critical threshold point; above and below this value, macroporosity and hydraulic parameters follow different functions with bulk density. For the first time, we demonstrate that soil bulk density can explain more than 50% of the variance of various physical and biogeochemical properties (e.g., soil organic matter content, pore structure, and carbon to nitrogen ratio), annual N$_2$O emissions as well as DOC pore water concentrations of peatlands. The more a peat-soil is degraded, the higher the risk of air/water pollution in peaty landscapes. Rewetting of highly degraded peatlands by the blocking of ditches is likely to be unsuccessful because soil moisture conditions are still enabling N$_2$O emission and preferential pathways through the soil may maintain high DOC export rates. The derived functions can assist in computing global matter fluxes from peat.

Understanding calcareous fen ecohydrology for protection and sustainable use

Alkaline and Cladium fens are peat-forming wetlands predominantly fed by groundwater that contains significant concentrations of calcium, magnesium and bicarbonate. Unique ecology encompassing small sedge and brown moss communities in a mosaic of different habitats is supported by specific hydrogeological and resultant hydrochemistry. They are protected under the European Union (EU) Habitats Directive (Council Directive 92/43/EEC) as Special Areas of Conservation (SAC) under habitat types 7230 and 7210 respectively, and as groundwater dependent terrestrial ecosystems (GWDTE’s) under the EU Water Framework Directive (2000/60/EC). Despite fens being an important part of the natural landscape in Ireland as well as one of the most threatened wetland habitats in Europe, there is little information on the hydrology and hydrochemistry that support these habitats. As part of a three-year research project (EcoMetrics) on GWDTE’s, an intensive hydro-chemical monitoring programme was set up in four Irish fen sites covering an eco-hydrological gradient from pristine to highly degraded conditions. Ground and surface waters monitoring started in July 2018 with spot monthly measurements supplemented by a continuous water table time series. Furthermore, monthly ground and surface water samples are taken and analysed for nutrients, major ions and metals. Additionally, geological surveys as well as vegetation surveys have been carried out in 2019. The hydrological and hydro-chemical evidence from each fen were then collated to build conceptual eco-hydrological models to represent both temporal and spatial variability in each geological setting. These models will then be used to define appropriate metrics that characterise the environmental supporting conditions in fens, as required for the EU Water Framework Directive. Here, the preliminary conceptual models will be presented as they are continuously updated by the ongoing data collection.

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Peatland rewetting and microbiota
Lake sediments in Amazonia are significant sources of methane, a potential greenhouse gas. Previous studies of sediments using $^{13}$C analysis found that the contribution of hydrogenotrophic versus aceticlastic methanogenesis to CH$_4$ production was relatively high. Here, we determined the methanogenic pathway in the same sediments ($n = 6$) by applying $[^{14}$C]bicarbonate or $[2-^{14}$C]acetate, and confirmed the high relative contribution (50 – 80 %) of hydrogenotrophic methanogenesis. The respiratory index (RI) of $[2-^{14}$C]acetate, which is $^{14}$CO$_2$ relative to $^{14}$CH$_4 + ^{14}$CO$_2$, divided the sediments into two categories, i.e., those with an RI $<$ 0.2 being consistent with the operation of aceticlastic methanogenesis, and those with an RI $>$ 0.4 showing that a large percentage of the acetate-methyl was oxidized to CO$_2$ rather than reduced to CH$_4$. Hence, part of the acetate was probably converted to CO$_2$ plus H$_2$ via syntrophic oxidation, thus enhancing hydrogenotrophic methanogenesis. This happened despite the presence of potentially aceticlastic Methanosarcinaceae and Methanotrichaceae in all the sediments. Alternatively, acetate may have been oxidized with a constituent of the sediment organic matter (humic acid) serving as oxidant. Indeed, apparent acetate turnover rates were larger than CH$_4$ production rates except in those sediments with a RI close to zero. Our study demonstrates that CH$_4$ production in Amazonian lake sediments was not simply caused by a combination of hydrogenotrophic and aceticlastic methanogenesis, but probably involved additional acetate turnover.

The rewetting of drained peatlands alters biogeochemical conditions in the peat and often leads to sustained elevated methane emissions. As a consequence, rewetted peatlands can remain net greenhouse gas (GHG) sources up to several years after rewetting. Although methane emitted from rewetted peatlands is produced by microbial activity, the distribution and activity of both methane producing (methanogenic) and methane oxidizing (methanotrophic) microorganisms is poorly understood. In this talk, we will outline our current understanding on the abundance and role of methane cycling key players in peatlands both pre- and post-rewetting. Further, we will report on a comparative microbial and geochemical study in two rewetted fens of the North-Eastern German Lowland Observatory TERENO-NE, 'Hütelmoor' and 'Polder Zarnekow'. Within the scope of the DFG Graduate School 'BalticTranscoast', we identified microbial controls for the sustained high release of methane from both fens. We could show that, unlike under natural conditions, methanotrophic bacteria in both sites were grossly underrepresented even several years after rewetting, while acetoclastic methanogens were highly abundant. Applying deep amplicon sequencing of reversely transcribed 16S rRNA gene transcripts and metagenomics, we further observed that in particular members of the Bathyrarchaeia but also putative anaerobic methane oxidizers of the ANME-2d clade (Candidatus M. nitroreducens) are abundant and potentially active in both fens. The relevance of these microbial clades for carbon turnover processes and the net release of GHG remains, however, to be clarified. Finally, we will present first results about the effects of the 2018 drought on microbial methane-cycling taxa in 'Hütelmoor' and 'Polder Zarnekow' and discuss potential microbial-targeted mitigation strategies accompanying rewetting projects.

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Peatland rewetting and microbiota

Freshwater wetlands sustain a highly active sulfur cycle that is not evident from the low prevailing sulfate concentrations. This explains the high sulfate reduction rates observed in peatlands and rice paddies, which not only drive cryptic sulfur cycling but also exert control on methanogenesis. Using metagenomics-driven discovery of yet unknown microorganisms, we discovered that the little investigated phyla Acidobacteria and Nitrospirae harbor representatives in peatlands and rice paddies, respectively, which encode the complete pathways of dissimilatory sulfate reduction. The novel peatland Acidobacteria encoded a highly versatile metabolism including polysaccharide hydrolysis, fermentation and hydrogen oxidation. Surprisingly, the genomes also encoded DsrL, which so far was only found in sulfur-oxidizing microorganisms, and the complete aerobic respiratory chain. This indicated the potential to revert the pathway of dissimilatory sulfate reduction for aerobic sulfur oxidation. In contrast, the novel rice paddy Nitrospirae was restricted to short-chained fatty acids and hydrogen as electron donor. This microorganism showed expression of the sulfate reduction pathway in gypsum (CaSO4)-amended rice paddy bulk soil as revealed by metaproteomics. In addition, it encoded the full pathway of dissimilatory nitrate reduction to ammonia (DNRA), which was expressed only in bulk soil without gypsum addition. The relative abundance of this microorganism was similar under both treatments indicating that it maintained stable populations while shifting its energy metabolism. Comparison to publicly available sequence repositories revealed a wide distribution of such novel Nitrospirae not only in freshwater but also in marine environments. Our results show that freshwater wetlands harbor novel microorganisms that not only affect cryptic sulfur cycling, but at the same time also other aspects of the intertwined biogeochemistry of these water-saturated soils.

Congruent effects of rewetting on pro- and eukaryotic peat communities in formerly drained temperate fens

Peatlands are major global soil carbon reservoirs and are widely distributed in Northern Germany. Their recent drainage for agricultural purposes has led to increased greenhouse gas emissions and loss of biodiversity. Rewetting of drained fens and paludiculture (“wetland farming”) is introduced to mitigate these negative impacts. However, the effects of rewetting on the assemblage dynamics of microbiota as important indicators of these impacts are still poorly understood. This study aims to investigate the seasonal dynamics of the diversity, community composition and network interactions of pro- and eukaryotes, and the influence of rewetting on these microbiological characteristics in formerly drained fens. Peat-soils were sampled seasonally from drained and rewetted sites of three mire types (costal mire, percolation mire and alder swamp) in Northern Germany. The pro- and eukaryotic communities were analyzed by sequencing 18S and 16S rRNA amplicons. The coastal peatland showed a lower biodiversity and more distinct relationship with the other two peatland types, which was due to the higher salinity in coastal regions. Prokaryotic and eukaryotic community compositions showed a congruent pattern, which was significant and mostly driven by site location and rewetting. By predicting functions from the microbial taxa, rewetting was found to significantly impact the important microbial processes, including methanotrophy, methanogenesis, nitrification, nitrogen fixation, sulfate respiration, fermentation and cellulolysis. Eight dominant modules were identified from the co-occurrence network, and these modules (that potentially drive certain functions) showed strong seasonal changes. These findings suggest that rewetting can strongly impact structure and functions of microbial communities, which may cause concerns regarding the emissions of greenhouse gases. These impacts of rewetting and seasonal changes should be considered in the practice of rewetting drained peat-soils.
Many peatlands have been affected by water table drawdown and carbon loss. Rewetting may push a drained peatland back towards its pre-degradation state and may result in renewed carbon accumulation, but there is little consensus on its effectiveness. Moreover, rewetting typically leads to a spike in methane emissions. Whether rewetting suffices to restore drained peatlands hinges to a large extent on whether microbial communities, and the functions they perform, are able to recover. We studied prokaryote communities in fens across temperate Europe using high-throughput amplicon sequencing of 16S rRNA, within the framework of RePeat (REstoration and prognosis of PEAT formation in fens – linking diversity in plant functional traits to soil biological and biogeochemical processes 2016–2019, BiodiVERSA). We included undrained, drained and rewetted fens to evaluate the effects of fen rewetting on microbial recovery. Prokaryote communities were highly stratified with depth, and there was a clear division between communities of drained and undrained fens. Prokaryote communities in rewetted fens were largely similar to those of undrained fens, but only where soil organic matter contents and bulk densities were respectively still high and low. Our results suggest that altered physio-chemical peat properties following drainage may hamper complete prokaryote recovery after rewetting.
Greenhouse gas emission & its drivers
Peatland restoration in Canada – Returning carbon sink function

Canadian peatlands cover 12% of the country’s land area and store approximately 150 Gt of carbon. However, Canadian peatlands are also under increasing pressure for resource extraction, with many disturbances converting these ecosystems into large carbon and greenhouse gas sources. Ecological restoration may return carbon and peat accumulation function to peatlands and has been highlighted as a natural climate solution. Over 25 years of research in partnership with the Canadian horticultural peat industry has resulted in the development of the moss-layer transfer technique for peatland restoration. Involving surface contouring, ditch blocking for rewetting, spreading donor material, and protection with straw mulch, this technique has been successful in establishing vegetation communities dominated by peatland species, including Sphagnum mosses. Moreover, this rewetting and vegetation establishment quickly returns carbon uptake, with ecosystem-scale measurements indicating sites can become annual carbon sinks within 15 years post-restoration. This long-term applied research program provides an excellent example of university-industry partnership that has resulted in an innovative ecological restoration technique. The improved understanding of peatland ecosystem function gained during this research program is now being used to develop restoration techniques for oil well-pads, access roads and open-pit mines. Results from the first few years post-restoration on restored well-pads and mines suggest that restoration actions can also set peatlands on a trajectory towards net carbon accumulation.

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Carbon and greenhouse gas balance of a black alder (Alnus glutinosa) ecosystem on organic soils

Natural peatlands are sinks of carbon but turn into significant sources when drained. Under forest use, organic soils can be sink or source depending on drainage status among other factors. However, disentangling carbon fluxes remains methodologically challenging. Alder stands are common in riverine lowland areas and fens. They are rich in nutrients and prone to high emissions of methane or nitrous oxide. Black alder is proposed as a climate-friendly option for forestry on wet or rewetted organic soil, but data is yet lacking. Here, we aim to quantify the carbon and greenhouse gas (GHG) balance of the organic soil pool of a wet black alder forest by combining eddy covariance and chamber measurements with tree growth modeling.

The Spreewald is a biosphere reserve in North-East Germany characterized by wet forests. At our site, main species are black alder and ash (Fraxinus excelsior). The mean stand age is 55 years and the mean canopy height 24 m. Groundwater levels were spatially and temporally highly variable and ranged from nearly constant flooding to less than -0.8 m in summer. Equally, soil organic carbon content and peat depth are heterogeneous. Fluxes of carbon dioxide were measured using the Eddy Covariance method for five years, while three sites were established for chamber based GHG measurements (ecosystem respiration, N₂O, CH₄). The sites represent typical soil and moisture conditions in the eddy footprint. Tree cores from 25 trees were analyzed for tree ring width for the last 20 years, while tree growth was measured for four years to model changes in above- and belowground biomass.

During all 5 years, the whole ecosystem was a carbon sink, while the soil organic carbon pool was roughly a net zero flux at stand scale. However, the fact that 16% of observed middle-aged trees died within 5 years of observation shows that the alders struggle with the current conditions. This raises doubts about the suitability of alder for fully rewetted conditions.

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Carbon dioxide and methane exchange of soils, trees and ditches in drained and rewetted fens

Drained fens frequently show high carbon dioxide (CO₂) emissions. Rewetting is a common measure of restoration, yet it can cause high methane (CH₄) emissions, which counteract the initial intention of climate change mitigation. In recent years, high CH₄ emissions from structural elements like ditches and tree stems also gained attention. While plantations of Black alder (Alnus glutinosa (L.) J. Gaertn.) can improve the uptake of CO₂, they can also act as a source of CH₄. Due to the often anoxic conditions and high availability of substrate, ditches can also be a strong source of CH₄ and CO₂. However, data on the emissions of trees and ditches are still scarce for the temperate region. Here, we present data on the exchange of CH₄ and CO₂ from the soil, tree stems and ditches in six temperate fens from the first 18 months of measurements of a three-year measuring period. The six study sites comprise three different kinds of fens including percolation fens, coastal fens and forested fens of which there is a drained and rewetted one for each type. We assessed the CO₂ and CH₄ exchange of the soil surface including herbaceous vegetation, tree stems, and ditches. In this way, we aim to evaluate the relative share of stem and ditch emissions compared to those of soil and herbaceous vegetation. At the same time, we show the wide range of values of greenhouse gas exchange that can occur in temperate fens across fen types and hydrologic conditions.

First results show that the hydrologic regime not necessarily is the main explanatory variable for CH₄ emission. Further, the fen ecosystems studied showed high variability in their water regime and hence their CO₂ and CH₄ exchange rates due to extreme climatic phases that prevailed in central Europe during 2017 and 2018. In addition, trees and ditches can contribute considerably to overall CH₄ emissions, however with large variation in time and space.

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University of Rostock

Seasonal dynamics of methane emitting microbiomes in drained and rewetted fens of Northern Germany

Drained peatlands with high organic carbon content are large sources of the greenhouse gas (GHG) carbon dioxide. Rewetting of peatlands is a promising strategy to protect the large C stocks, however, rewetting also causes increased emissions of the potent GHG methane (CH₄). The net climate effect of rewetting and the role of the microbiome remains uncertain. We investigated the differences between three pairs of drained and rewetted fen microbiomes across seasons and identify links between CH₄-cycling functional guilds and magnitudes of methane emissions.

DNA was extracted from seasonally sampled profiles at 5–10 cm, 15–20 cm and 25–30 cm below peat surface. Analyses comprised coenzyme:M reductase subunit A gene (mcrA) qPCR, Illumina MiSeq analysis of total prokaryotic 16S rRNA gene amplicons, moisture, redox potential, dissolved organic carbon (DOC), and gas flux measurements.

Methanogens were more than tenfold more abundant in rewetted than in drained fens (10⁶–10⁷ vs. 10⁵–10⁶ mcrA copies per gram soil). Abundance was lowest in the brackish coastal mire. Seasonal variations were strong, with highest methanogen abundances in winter. Microbiome composition was fen type-specific, but was similarly impacted by rewetting, with higher prevalence of (facultative) anaerobic taxa. Preliminary data indicate soil moisture, redox potential and salinity as drivers of microbiome composition and methanogen abundance, with the latter being correlated to observed CH₄ fluxes.

As hypothesized, higher abundance of methanogens in rewetted fens could be shown. However, coastal fens with their lowest methanogen abundance are suggested as ideal sites for rewetting due to their potentially lowest methanogen abundance and thus CH₄ emissions.

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Methane production in Central European fens is linked to edaphic properties, not large scale climatic gradients

Percolation mires were sampled at twelve locations across Europe, spanning 4.5 degrees of latitude and representing a nearly 4ºC gradient in mean annual temperature. At each location, the concentration of dissolved methane (CH₄) was measured in drained, restored, and undrained peatlands at three depths (0–5, 15–20, 45–50 cm) during the height of the growing season. Linear models were used to explore the effects of management, depth, climate, and physicochemical edaphic properties on CH₄ concentration. CH₄ concentration was consistently lower in drained peatlands, as compared to restored and undrained peatlands, likely due to a lack of the anoxic conditions that promote methanogenesis. In all management types, significantly less CH₄ was measured in the shallowest soil layers, although this likely reflects the impacts of diffusion to the surrounding air, rather than a meaningful gradient in CH₄ production. Due to negligible CH₄ concentrations in the drained peatlands, the effects of climate and physicochemical edaphic properties were explored only in undrained and restored peatlands. CH₄ concentrations did not vary significantly across the European climatic gradient irrespective of management type. Variation in CH₄ concentrations was best explained by Fe and SO₄ levels in the peat. Furthermore, CH₄ production rates were determined for soil samples from each of the three depths in restored and undrained sites, where anoxic processes are dominant throughout the peat profile. Root-free soil samples were made anoxic and CH₄ production rates were determined in high temporal resolution over five days. CH₄ production rates were highest in the shallowest soil layers, regardless of management type, but restored peatlands consistently had lower CH₄ production rates than undrained peatlands.

Effects of carbon exchange uncertainties in estimating peatland radiative forcing over the Holocene

Changes in peatland carbon budgets affect the global carbon balance and concentration of greenhouse gases in the atmosphere. Quantitative reconstructions of peatland carbon dynamics enable us to reconstruct the impact on the climate by peatlands, i.e. radiative forcing (RF). Reconstructions of RF during peatland development show that at first the climate warming effect of CH₄ emissions exceeds the cooling effect of CO₂ uptake, but after a period that can last several millennia the overall effect of most peatlands will move towards a cooling effect, in which case an overall positive RF switches to negative. However, reconstructing peatland carbon dynamics deals with uncertainties related to carbon uptake and release, CH₄ emission rates, and peatland expansion rates. We investigated the effect of these uncertainties on the RF of three Finnish peatlands with reconstructed carbon dynamics. Taking into account temporarily stored carbon, due to it being decomposed and lost since uptake, increases the reconstructed past cooling effect of CO₂ uptake, but the effect on current RF is minimal. Accounting for previously decomposed carbon can shorten the period of positive RF before switching to negative with up to 4000 years. Including fire effects on carbon storage has only small additional effect lasting shorter than 1000 years. The largest uncertainty in reconstructing peat carbon dynamics lies with CH₄ emissions, and its uncertainty affects RF more severe than that of CO₂ uptake. Peat expansion rates control cumulative CO₂ and CH₄ fluxes over the peat area. Advanced expansion causes the RF to peak earlier, because CH₄ emissions are more directly controlled by peat surface area, but also an advanced switch-over from positive to negative RF. The uncertainties of present day climate forcing due to long term peatland carbon exchange can be ranked as uncertainties in CH₄ emission > timing of peat expansion > temporary carbon storage.
**The effect of topsoil removal and *Sphagnum* spreading on the net greenhouse gas balance of a rewetted peat bog**

The restoration of degraded peatlands, which are global hotspots for greenhouse gas (GHG) emissions and carbon (C) stocks, was found to be a measure to re-establish key ecosystem functions of these ecosystems. In Germany around 5% of the total GHG emissions derive from drained peatlands. However, restoration by rewetting often results in high CH₄ emissions counteracting a reduction in CO₂ and N₂O emissions. Therefore, we compared fluxes of the three most important GHGs from six different restoration approaches with stabilized water tables to those of a drained control. The field trial was implemented on a former, intensively used bog grassland. Restoration ranged from rewetting directly on the original surface to rewetting after topsoil removal (TSR) and additional spreading of *Sphagnum* spp. as target vegetation. Measurements included discontinuous GHG flux sampling with closed chambers, vegetation height, water table and climate parameters from September 2017 to September 2018. Artificial neural networks (ANNs) were used for gap-filling CO₂ fluxes with continuously sampled environmental parameters to obtain annual CO₂ budgets. Annual CH₄ and N₂O budgets were derived by simple linear interpolation. It turned out that the rewetted plots with original surface cover did not improve the net GHG balance due to high CH₄ emissions. In contrast, TSR reduced the net GHG emissions (in CO₂-eq.) by, on average, more than 30-90 t ha⁻¹ a⁻¹ compared to the control and the original surface plots. Spreading peat mosses further improved the net GHG balance towards an additional GHG uptake of up to 5 t ha⁻¹ a⁻¹. The combination of rewetting, TSR and *Sphagnum* spreading was the only restoration approach resulting in a net C uptake by the ecosystem. Therefore, we suggest that restoration management of drained bog peatlands must exceed rewetting directly on the original, degraded surface and rather remove the upper decomposed peat layer and spread target vegetation, e.g. *Sphagnum* spp.

**Do cover fills reduce peat oxidation and carbon emissions from managed organic soils?**

Peatlands have served as important carbon sinks in the past. The agricultural use of organic soils usually requires drainage thereby transforming these soils from a net carbon sink into a net source. Besides CO₂ emissions from peat oxidation, drainage also results in subsidence of organic soils. The drainage system requires a periodic renewal to sustain agricultural use. Finally, pumping systems are used after progressive subsidence. In Switzerland, there is a high demand for maintaining agricultural use of organic soils while simultaneously reducing environmental impacts. One solution may be to cover the organic soils with excavated mineral soil material to improve the productivity without the costly step to renew the drainage system. Previous studies showed that the agricultural use seems to benefit from this measure; however, the impact on the greenhouse gas balance is unclear. Our study site, established in 2018, is situated in Rüthi, St. Gallen, Switzerland on the former flood plain of the Rhine River. In the 1970s, the land was drained, pastures established and intensively managed since then. Over time, agriculture became problematic since the topsoil was water-saturated most of the season. To ensure the existence of the farm located at the study site, it is planned to cover 30 ha with excavated soil material. As a pilot project, 2 ha were covered with 30 to 50 cm silty material already in 2006. The aim of the project is to evaluate the impact of soil coverage on the greenhouse gas balance. The carbon balance of the covered and the adjacent reference site is measured with an Eddy-Covariance system starting in March 2018. N₂O measurements started in 2019 by using the chamber method. In addition, the ¹³C signature of the emitted CO₂ will be measured occasionally to differentiate between carbon deriving from old peat and from newly formed soil organic matter. First results of the carbon balance of the two sites will be presented.
Spatial and intra-annual variations of CO₂ exchange on rewetted milled peatlands

In the northern hemisphere, large-scale restoration of peat excavation areas is on-going. So, convenient methods are needed for estimating CO₂ fluxes and their spatial distribution on recovering peatlands. We will discuss the possibilities of using drones with multispectral cameras to monitor vegetation recovery and from that estimate spatial distribution of CO₂ fluxes on restored milled peatlands in addition to analysing relations between plant functional type biomass and CO₂ fluxes. The study was carried out on three recovering milled peatlands in N-Estonia, which have been rewetted, or restored using the moss-transfer technique (Rochefort et al., 2003) from 2005 to 2012. CO₂ was measured using transparent chambers, and vegetation analysed in 2015 and 2016. In September 2017, Normalized Difference Vegetation Index (NDVI) quantifying the photosynthetic capacity of the land cover was measured with a mapping drone with multispectral camera. The driest site, with lowest water table was a CO₂ source during the two growing seasons, but had significantly smaller CO₂ emission values compared with unrestored abandoned milled peatlands. CO₂ uptake increased with higher plant coverage and LAI, Eriophorum vaginatum cover and biomass and Sphagnum cover, while plots with bare peat remained to be CO₂ sources in both measurement years. Respiration was higher with higher coverage of dwarf-shrubs. NDVI explained about 25% of the variation in Net Ecosystem Exchange, CO₂ uptake was higher on plots with higher NDVI values (which indicates higher amount of photosynthetically active biomass). Spatial distribution of NDVI values obtained with drones equipped with multispectral cameras may give us valuable information about vegetation, weather and water table conditions, and temporal changes in photosynthetic capacity on recovering peatlands.

Restoring degraded peatlands with rice cultivation: Evaluating greenhouse gases and soil C dynamics

Subsided wetlands caused by agricultural practices are a major source of greenhouse gases. In addition, loss of levee integrity to maintain agriculture on peat soils is at risk of degrading water quality and pose serve water infrastructure issues. We examined restoration of peat soils with rice cultivation. The experimental design included soil C contents ranging from 2 to 26%. Rice straw was shown to increase 3-fold dissolved organic C, with the largest priming effect observed in 15% soil C. The release of DOC from the PE of rice straw was associated with the reduction of Fe³⁺ to Fe²⁺. The dominant source of DOC was from rice straw, however the primed DOC did not result in a proportional increase in CH₄ production. The contribution of soil C to CH₄ production increased from 30 to 50% as SOC increased. To understand the effect of N fertilization, CH₄ and N₂O emissions were monitored in an N rate trial using an in-situ pulse ¹³CO₂ labeling approach. Both CH₄ and N₂O emission were unaffected by N rates up to 160 kg ha⁻¹, however, increasing N rates increased plant derived DOC. Across N treatments, plant derived C contributed 27% to emitted CH₄, and up to 9.1% of DOC. N₂O consumption was observed across all N rates. Nitrous oxide consumption was related to SOC content with the highest rates of 8.2 tons of CO₂ equivalents ha⁻¹ a⁻¹ in high C soils corresponding to 32% of the average CO₂ emissions from drained peat soils. The highest N₂O consumption rates occurred during soil drainage associated with rice operations. Overall, N fertilization decreased CH₄ emissions particularly in low C soils. Annual budgets of N₂O emissions were not affected by N fertilizer regardless of soil C content. The capacity of restored wetlands to act as an atmospheric N₂O sink is significant and can be made stronger by manipulating water depth. The use of rice cultivation to restore degraded peat soils generally emitted less GHG than business as usual crops grown under drained conditions.
Greenhouse gas emission & its drivers

Terrestrial models predict fluxes of carbon and water and more recently also N in the earth system. Some models can be integrated into earth system models to predict the biotic feedback to climate change. Earth system models predict feedback to global change. A comparison of earth system models showed that one of the largest uncertainties in predicting biotic feedback to climate change is how the soil will respond. Microbial processes in wetlands are subjected to waterlogging and in many cases fluctuating water tables. Waterlogging reduces decomposition rate, and some models include that. However, there is good reason to believe that not only the rate, but also the quality of decomposition is different under waterlogging. For example, we know that lignin cannot be degraded without oxygen, and there are also other decomposition products formed (e.g. methane). Accumulation of peat that is then quite quickly lost upon drainage also suggests that material that can be degraded under aerobic conditions accumulates under anaerobic conditions.

Here we attempt to include decomposition under anaerobic conditions into MIMICS. The model has two pools of litter with different decomposition rates, and we assume that waterlogging reduces the rate of the slowly degrading pool the most. The model also has two groups of microbial populations, r- and K-strategists. Here we use data from measurements in pristine, degraded and re-wetted fens to parameterize and test MIMICS for waterlogged and non-waterlogged peat. In this way, we hope to understand how anaerobic conditions will affect the microbial community and how that might affect decomposition. We also hope to predict effects of draining and re-wetting fens.

Modelling carbon cycling in wetlands

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Plant growth & decomposition
Productivity gradients, vegetation processes, and ecosystem functions in fens. What’s known and what’s still hidden?

Fens exhibit notable variation in productivity due to regional and local environmental gradients. Their impact on vegetation processes and ecosystem functions, including peat formation, is still insufficiently understood. This problem is central also in fen restoration, where nutrient remobilisation from mineralised peat often results in eutrophication. I review results of studies which analysed environmental preconditions of productivity gradients in fens and their linkages to species pool filtering, plant functional diversity, individual plant growth and biomass allocation ratios, as well as decomposition patterns. I first demonstrate that productivity is a dominant factor in fens controlling species and functional diversity, as well as plant performance and biomass allocation ratios, mainly through competition for light. Then I report on a recent study (project REPEAT) which quantified productivity and decomposition potential of moss and sedge species dominant in different zones of natural riverine fens of NE Poland. We found a strong shift of production from mainly mosses and roots in groundwater-fed sites to predominantly shoots in surface water-fed riverine sites. A similar shift in root:shoot ratios along the nutrient gradient was also found in sedges grown in mesocosms. Moss species grown in the lab exhibited various responses to nutrient gradients (unimodal and monotinous), which partly explains their displacement along field gradients. Decomposition potential of sedge roots (from field and ex-situ experiments) and mosses (field) was assessed based on lignin and cellulose contents, revealing clear between-species differences and generally higher decomposability in species of eutrophic sites. However, decomposition rates measured in the field using litter bags with autochthonous material showed surprising-ly little relation to (any components of) primary productivity (but strongly responding to depth under peat surface). I further discuss how productivity impacts fen stability and whether it is sufficiently taken into account in restoration projects, which generally fail in restoring nutrient limitation levels similar to those of reference fens. Finally, I point to challenges for future research, which I mainly see at interface between plant, fungal and microbial sciences.

Production and decomposition of plant biomass in three temperate peatland types of Central Europe

Primary production and decomposition of plants determines the amount of carbon input into peatlands and represents a key factor in the overall assessment of the carbon budget. Peat is formed when the production of plant material exceeds their decomposition, e.g., due to anoxic conditions. To reduce GHG emissions, formerly drained peatlands are re-wetted to restore low decomposition rates and their potential as carbon stores. We compared plant biomass production and decomposition in-situ in three temperate peatland types of Central Europe, each in a drained and in a re-wetted stage. Fine root production was assessed with ingrowth cores, and decomposition of leaf and root litter with litter bags. We used tea bags as standard material to gather data about decomposition rates comparable between the different peatland types. For all sites and treatments, fine root production was highest in the upper depths. We found faster root decomposition in the drained sites of the alder carr and percolation mire compared to their re-wetted sites, but not in the coastal mire. Differences between production and decomposition between the treatments depended on the peatland type, hence, on the dominant plant composition. Overall, decomposition was lowest in the percolation mire and highest in the alder carr. Our results underline that the difference of peatland types in hydrology, chemistry, and, thus, plants composition reflects in different patterns of fine root production and decomposition. In our study, the re-wetted percolation mire seems to have the highest peat accumulation potential with low decomposition rates and relatively high production compared to the other sites.
Root growth phenology of common sedge species in response to increasing levels of nutrient availability

Roots are key players in many important ecosystem processes, such as water and nutrient uptake and carbon fluxes to the soil. Deep understanding of root phenology is of special importance in lowland fens, which are one of the most effective carbon stores on earth, and where roots and rhizomes are the primary source for peat formation. Here, both timing (phenology) and amount of root growth matter, but are understudied. We used a mesocosm experiment in which we non-destructively monitored root growth amounts and phenology to gain mechanistic understanding of root growth responses of different sedge species, as well as the same species from different origins, to increasing levels of nutrient availability. Root growth of two different depth levels (permanently anoxic and partly oxic conditions) will be reported, and put into the context of emerging root phenology studies in peatlands of the temperate and subarctic zone. Our results will not only improve our understanding of sedge root phenology and its drivers, but also aid policy makers in deciding which species are suited best for restoration efforts under certain nutrient levels.

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Roots, tissues, cells and fragments – how to characterize peat from drained and rewetted fens

One aim of the WETSCAPES project is to characterize macroscopic and microscopic remains in rewetted peat soils. Here, remains in different stages of preservation occur intermixed as old and new material. By means of high resolution analyses, the composition of the peat material spanning from coarse structures to amorphous matrix in different degrees of decomposition are described and quantified.

We focus on the deposits of two percolation fen sites, one drained (Bad Sülze) and one rewetted (Tribosees). We recovered one peat monolith per site that was then frozen and subsequently cut into contiguous 0.5 cm slices of 6 × 12 cm. Subsampling of these slices allows macro- and microscopic analyses in close spatial linkage to additional microbiological, soil-chemical and physical analyses.

Using standard macroscopic analysis (magnification × 40) we distinguished and quantified morphotypes that indicate different degrees of decay. Well-preserved material – especially rhizomes and rootlets – are easy to detect, but part of the more strongly decomposed material can only be broadly classified as detritus. When the proportion of detritus increases, this component is of greater interest. We studied the detritus component microscopically (magnification × 400). Besides pollen, we found a large array of non-pollen palynomorphs (NPP) covering diverse kinds of tissue, cell clusters and even single cells, as well as micro algal remains, fungal tissue and spores.

Combining macro- and microscopic methods allowed us to identify several microscopic plant remains: radicle fragments, vascular tissue, epidermis cell clusters, infills of cells, and ‘pustules’ (cell fragment that form the basal part of root hairs). We can now identify a number of microscopic plant remains at the level of the family or order (e.g. Poaceae, Cyperaceae or Poales) or even (although rarely) at the species level (pustules characteristic for Carex limosa).

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Research on peat-formation in living mires is, up to now, strongly focused on Sphagnum-dominated, acid-oligotrophic, and rainwater-fed bogs. Such mires dominate in boreal and temperate-oceanic regions. Anthropogenic degradation has affected a large fraction of mires more suitable for agriculture in temperate continental, meridional and (sub)tropic regions. These regions are dominated by groundwater-fed, often base-rich and rather eutrophic fens. In contrast to bogs, fen peat is formed by roots and rhizomes of sedges, grasses and woody plants growing into an already existing matrix. This “displacement peat” therefore consists of a mixture of material from different times and requires new approaches in chrono-stratigraphical research.

For high-resolution analyses, we sampled peat monoliths of drained and rewetted sites in a percolation mire, a coastal wetland, and in alder carrs. The monoliths were cut into 0.5 cm contiguous slices, which were subsampled for a set of analyses: micro and macro fossils, microbial DNA, and soil chemistry. Here, we present results from a percolation mire that was deeply drained for agriculture in the late 1960s. The site was rewetted in 1997 and is now water-logged during the whole year. Vegetation is dominated by Carex species. The monolith includes about 10 cm of newly formed material (litter, roots) underlain by a 25 cm thick layer of compacted, highly decomposed, amorphous peat material. Below this layer lies the well preserved original peat; the top of this original peat has been radiocarbon dated to ~3,700 cal. BP. These different layers show clear differences in the micro and macro fossil record. Based on the radiocarbon date, bulk density, and ash and carbon content of the peat samples, we calculated the loss of peat during the 30 years of intensive agriculture. Gas flux measurements have shown that the site today is again a net C sink. We try to reconcile the measured fluxes with the newly accumulated carbon in the profile.

Below-ground plant structures are inherently difficult to observe in the field. Sedge peat that mainly consists of partly decayed roots and rhizomes offers a particularly challenging soil matrix to study (live) plant roots. To obtain information on plant root systems, research commonly relies on rhizotrons and excavations. Computerized tomography (CT) of peat cores cannot sharply distinguish between (dead) plant material and water and even in dried cores, no distinction can be made between live and dead roots. Moreover, controlled drying of large monoliths is cumbersome and time consuming. Here, we present a low-budget method for the three-dimensional visualisation of root systems in peat monoliths.

A peat core was extracted using a large diameter (20 cm) coring device and deep frozen at -18 °C. A monolith of 6 × 13 × 40 cm (h × w × l) was cut from the core and brought to -4 °C. Thin slices of 0.5 mm were cut from the frozen monolith using a paper block cutter (the so-called DAMOCLES device) and the freshly cut 6 × 13 cm surface of the monolith was photographed after each cut. A 3D model of the live roots could be reconstructed from the resulting image stack based on computerized image handling, including pre-processing, filtering, segmentation and visualisation. Different types of image analysis software were used, comparing open-source and licensed applications. For the vital step of image segmentation, different approaches were tested including semi-automatic segmentation with machine-learning algorithms.

Digital visualisation techniques of roots in peat

A focus on displacement peat, peat losses, and new accumulation in a rewetted, former drained fen
In-vitro biomass production of different peat moss species

Peat mosses (*Sphagnum* spp.) have similar physical and chemical properties as slightly humified peat and therefore may provide a sustainable alternative for peat in horticultural substrates. In several projects, *Sphagnum* is successfully being cultivated on rewetted degraded bogs (‘Sphagnum farming’), showing the feasibility of this new kind of agriculture. One major bottleneck for large-scale implementation is currently the lack of sufficient volumes of high-quality *Sphagnum* vegetative seeding material to establish new *Sphagnum* cultivation sites. Our collaborative project MOOSzucht (BMEL funding No. 22007216; www.mooszucht.paludiculture.com) addresses this issue by 1) collection, genetic characterization and selection of highly productive wild *Sphagnum* provenances (University of Greifswald), 2) establishment and optimization of axenic in-vitro propagation of *Sphagnum* in photobioreactors (University of Freiburg), 3) design and construction of a photobioreactor for large-scale propagation of *Sphagnum* (Karlsruhe Institute of Technology), 4) optimization of non-axenic mass propagation of *Sphagnum* on irrigated fleece (Niedersächsische Rasenkulturen NIRA GmbH & Co. KG) and 5) testing vegetative seeding material under field conditions (University of Greifswald).

In-vitro cultivation techniques for peat moss culture have been established on a laboratory scale. However, bottlenecks still exist in upscaling the cultivation process to become economically viable. Axenic cultures of 20 *Sphagnum* species have been established and the most productive clones were determined. Further, growth of monoclonal strains in 5 L photobioreactors will be improved by optimizing light intensity, aeration and feeding schemes. The peat moss material grown in the 5 L bioreactors will be used as starting material for large-scale production.

Parameters for rapid *Sphagnum* lawn establishment

In glasshouse and field experiments we investigated parameters accelerating the establishment of a new *Sphagnum* lawn (>90% cover of vital *Sphagnum*) starting from fragments since *Sphagnum* has a high vegetative regeneration potential. We tested: *Sphagnum* species, initial cover, fragment sizes, including different moss lengths with and without capitulum, and protective covers.

In the glasshouse, we used standard seed trays, filled with sterile low decomposed peat (H3-5), where moss fragments of different *Sphagnum* species were manually spread and cultivated for several months under controlled conditions. The field trials were carried out in rewetted degraded bogs in NW Germany. The mosses were spread on the bare even peat surface. Continuously wet conditions were ensured by sprinkling in the glasshouse and successful irrigation via ditches in the fields. The establishment of a new *Sphagnum* lawn was more rapid the higher the cover of *Sphagnum* founder material (>80%) was. Large fragments (5 – 10 cm) increased faster in length and cover than small fragments (0.1 – 0.3 cm), in particular in the field. The upper centimetres of the *Sphagnum* moss (0 – 5 cm) produced the largest quantities of new shoots and thus are the most suitable *Sphagnum* parts for spreading. Protective straw cover should not exceed 3 cm thickness to allow sufficient light to reach the *Sphagnum* fragments. If sufficient water supply can be ensured, covering *Sphagnum* fragments is unnecessary to protect against desiccation. Results are applicable for both bog restoration and *Sphagnum* farming.

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Growth and xylem anatomical adjustments of *Alnus glutinosa* after the rewetting of a drained swamp

Human-driven peatland drainage has occurred in Europe for centuries, causing habitat degradation and leading to the emission of large amounts of greenhouse gases. In the last decades, there has been an increase in policies aiming at restoring these habitats through rewetting. Alder (*Alnus glutinosa* L.) is a widespread tree species in temperate peatlands, and it is adapted to high water table levels. However, little is known about growth and wood anatomical adjustments of this species to changing water table levels and thus, to rewetting actions. In this study, we focus on two neighbouring alder carrs in northern Germany. One of them underwent a rewetting process in 2005 and is under waterlogged conditions most part of the year, whereas the other one is a drained alder carr in which the water table remains below the soil surface year-round. In 2018, we took increment cores from five trees at each site, cut them with a rotary microtome, stained them and fixed them in permanent microslides. We took high-resolution images under the microscope and proceeded to quantitatively analyse xylem anatomical traits for the period 1993 – 2017 with the software ROXAS. We measured vessel lumen area and density, vessel grouping, theoretical hydraulic conductivity and cell wall thickness. In addition, we x-rayed a second core for each tree in an ITRAX-multiscanner to measure wood density and ring width. Whereas wood density did not respond to the waterlogging conditions, both hydraulic efficiency and growth decreased after rewetting. The adjustments of alder trees to waterlogging conditions are discussed from a hydraulic- and a carbon sequestration-related perspective, emphasizing the implications of rewetting actions for the performance of alder trees and their habitat.

Intra-annual growth dynamics of alder (*Alnus glutinosa*) from rewetted and drained alder carrs in northeastern Germany

With the current drive to restore as many of previously drained peatlands as possible, the question of the effects of rewetting on standing trees in drained wooded peatlands arose. In general, after peatland rewetting, tree growth is depressed, and tree mortality rates are higher than at drained sites. However, there is little information about tree-growth dynamics at intra-annual scales. Alder is one of the most common tree species growing on and near peatland sites in Germany. We therefore monitored intra-annual variability of alder tree growth patterns and water levels from one drained and one rewetted alder carr in Northeast Germany. We installed dendrometers on ten alder trees in total (five from each site) with the temporal resolution of 1 minute to continuously monitor stem radius variations. We compared tree growth patterns of these ten dendrometer time series over the last two years by decomposing them according to tree growth phases and estimated the differences between the phase onsets at the two sites. At the same time, we evaluated drought stress by integrating the curves of tree water deficit and comparing both stress durations and levels. We found that trees from the rewetted alder carr had a shorter growing season, depressed growth, but were also less sensitive to drought stress than the trees growing at the drained carr. Further, the observed variations in the growth dynamics at both sites coincided with the relative elevation above peatland level upon which the trees grew. Therefore, our results indicate that alder response to rewetting might be complex and strongly influenced by micro-site conditions.
Peatland rewetting and vegetation
The role of lateral and tree transport in methane cycling in tropical peatlands

Tropical peatlands in Southeast Asia have sequestered carbon over thousands of years and are an important global carbon stock. In natural peat swamp forests, high water levels inhibit decomposition of carbon due to anoxic conditions, which are prolific conditions for increased methane (CH₄) emissions, a powerful greenhouse gas known to emit in significant quantities from tropical wetlands. Despite these conditions, CH₄ measurements from peat surfaces using chamber methods in tropical peatlands have yielded CH₄ emissions nearly two orders of magnitude lower than measured in temperate and boreal regions. Theories including low rates of methanogenesis and high rates of CH₄ oxidation near the peat surface and tree root-peat interface have been suggested. Here we propose an alternative CH₄ transport theory. Using a suite of field measurements collected in a pristine peat swamp forest of Brunei, we propose that the observed low CH₄ fluxes from the peat surface are resulting from 1) lateral transport and 2) tree transport. Both these CH₄ transport have not been fully measured from any of the tropical peatland which may have led to the earlier lower CH₄ estimates.

Alder tree rings as recorders of environmental and climatic fluctuations--a review

Although alder wood is frequently found in belowground constructions and often preserved in wet soils and peat, its ring width is rarely used as a proxy for reconstructions of environmental or climatic conditions. Due to the specific growth conditions at lakeshores, rivers and in waterlogged soils and peats, the environmental signal stored in the annual variance of alder ring-widths is highly site-specific and not dominated by one climatic factor. We review existing dendrochronological studies based on alder and show that depending on the conditions the trees experience during their establishment, their reaction to water table fluctuations can be very different--ranging from positive to negative growth responses to the same water table variation. Site hydrology i.e. groundwater table turned out to be most influential when variable, but at sites with more stable hydrological conditions, temperature during- and length of the growing seasons were identified as the main factors influencing radial growth of alder. Given the case that crossdating of historical and subfossil alder wood over larger regions is possible, we conclude that existing long chronologies are likely built from sites with predominantly stable hydrological conditions (i.e. mineral soils) and can therefore be used as indicators/proxies of temperatures during the growing season.
Peat formation under pressure? Effects of machine mowing on soil and below-ground plant properties in temperate fens

A promising alternative to drainage-based land use is paludiculture, i.e. agriculture and forestry on wet and rewetted peatlands with preservation of the peat body and possibly new peat formation. Such new management practices involve using site-adapted (low ground pressure) machinery. The effects of machine mowing on the wet peatland ecosystem are poorly understood. Within the EU BiodivERsA project REPEAT (REstoration and prognosis of PEAT formation in fens – linking diversity in plant functional traits to soil biological and biogeochemical processes, 2017 – 2020), we have studied machine mown and unmown near-natural and restored wet percolation fens in the Netherlands, Germany, and Poland. We hypothesize that machine mowing in wet fens leads a) to a lower cover of potentially peat-forming plants, b) to a relocation (but no change) in overall below-ground biomass stocks, c) to higher bulk density and penetration resistance, and d) to a smaller decomposition rate of below-ground biomass. The hypotheses are largely based on knowledge from mineral soils and drained peat soils. Species composition has been studied by comparing vegetation relevés with regard to the occurrence of peat-forming species and functional groups. Below-ground biomass production in different depths has been assessed in ingrowth cores. Penetration resistance has been measured using a penetrometer. Decomposition rates have been assessed using litter bags with local root material and standard materials at different depths over 3 and 12 months. In a subset of sites, the long-term (>5 years) impact of a light tractor with wide tyres compared to a heavy tracked machine has been assessed, and additional properties (e.g. root porosity) were included. Knowledge about alterations of peat and vegetation due to machine mowing is crucial from a conservation point of view as well as for understanding peat formation and assessing restoration effects.

Vegetation development is a major yardstick for successful peatland restoration and is tightly linked to the potential of peatlands to sequester carbon. Hence, a quantitative assessment of vegetation development is required to evaluate peatland restoration practices regarding the re-colonization of target species and implications for the C sink function. Continuous, non-destructive canopy metrics obtained from digital RGB imagery become increasingly popular in observational ecosystem studies.

Here, we evaluate the applicability of plot-scale vegetation metrics, namely vegetation height and greenness, as proxies for succession and treatment effects in a peatland restoration study. The experiment comprised a reference plot with intensive grassland species and six restoration plots. During the course of our study, the plots were covered to a different degree with graminoid species and peat mosses. In a second step, we evaluated the suitability of these plot-based vegetation indices as predictors for CO₂ exchange dynamics using artificial neural networks. Accurate prediction of CO₂ exchange dynamics is of special concern in plot-scale field trials, where greenhouse gas budgets are commonly obtained from modelled flux time series based on biweekly to monthly closed-chamber measurements. Our results show that both greenness and vegetation height can quantitatively track restoration-induced vegetation dynamics and harvest effects on the plot scale. Vegetation height was more sensitive to harvest events, whilst plot greenness better represented the lateral spread of peat mosses. Implementing these vegetation indices as predictor variables in artificial neural networks improved the plausibility of gap-filled CO₂ flux time series, which ultimately leads to more accurate budgets. This suggests that vegetation indices derived from RGB photography and vegetation height measurements are simple and effective tools for tracking the success of plot-scale restoration projects.

Using plot-scale greenness and plant height to monitor vegetation development in peatland restoration trials

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Peatland rewetting and greenhouse gas emissions
Peatland rewetting: Balancing methane emissions against carbon dioxide savings

Peatlands store disproportionately much carbon per unit area compared with other ecosystems. However, peatlands lose this carbon store upon disturbances like drainage for agriculture/forestry or peat fires. Peatland rewetting is commonly seen as beneficial for climate change mitigation, because it effectively stops emissions of carbon dioxide ($CO_2$) from the peat. Yet, rewetting induces anaerobic conditions near the surface leading to methane ($CH_4$) emissions. While $CH_4$ is emitted in relatively small amounts by almost all peatlands, emissions can be much higher in recently rewetted peatlands at least in the first years. Both greenhouse gases ($CO_2$ and $CH_4$) vary strongly with respect to their atmospheric lifetimes and radiative forcing effects, complicating conclusions about the climatic benefits of peatland rewetting.

Here, we balance the increase in $CH_4$ emissions following peatland rewetting against the savings by avoided $CO_2$ emissions for a number of example peatlands. We compare several global warming metrics and modelling approaches and identify how the choice of metric influences the combined greenhouse gas effect and, consequently, the conclusions that are drawn regarding rewetting success.

Drought events in rewetted peatlands: Can rapid vegetation succession compensate for respiratory $CO_2$ losses?

Hydrology is arguably the most important regulator for succession dynamics and carbon dioxide ($CO_2$) budgets in peatlands. The year 2018 represents an extraordinary drought year in Central Europe in terms of meteorological records since 1850. In this study, we addressed the drought effect on vegetation development in a rewetted coastal fen using multisensory drone data and a Random Forest Classifier. We further investigated the implications of the drought-induced vegetation change for the peatland’s $CO_2$ exchange in that particular year.

Since the fen had been flooded for nature conservation purposes in 2010, succession dynamics were low and the site was characterized by a patchy mosaic of open water areas and a few competitive species ($Phragmites australis$, $Schoenoplectus tabernaemontani$, $Bolboschoenus maritimus$, $Carex$ spp.). After the fen dried out completely in summer 2018, aerial imagery revealed the formerly open water areas to be rapidly colonized by new plant species ($Tephroseris palustris$ and $Ranunculus sceleratus$). Whilst the drought substantially lowered photosynthetic $CO_2$ uptake of the established vegetation in summer, the subsequent colonization of the formerly flooded areas with new species created a second $CO_2$ uptake peak in autumn. The rapid growth of new plants could therefore partially compensate for a drought-induced increase in respiratory $CO_2$ loss so that the peatland could remain a net $CO_2$ sink in a year of extreme drought.

Our study indicates how extreme events can disrupt periods of stagnant vegetation development and how the colonization of new species can buffer drought-induced $CO_2$ losses in flooded peatlands.
Patterns of greenhouse gas fluxes for a restored wooded wetland in Denmark

Previously drained forested wetlands in Denmark are being restored for biodiversity, but the impact on the greenhouse gas (GHG) emissions in these systems is limited. Whereas the reduction in the net CO₂ emission after rewetting is well documented, high uncertainty for CH₄ and N₂O fluxes remains, making accurate projections of the long term impact of rewetting on GHG budgets difficult. On top of that, CH₄ and N₂O fluxes exhibit a dynamic spatiotemporal variation tied to the soil hydrological regime requiring a high number of flux measurements in space and time as well as their environmental drivers. We will present preliminary results of the spatiotemporal patterns of GHG fluxes in a restored wooded wetland in Gråbek, Denmark. The results are obtained using an automatic chamber system, called SkyLine2D, to derive high frequency measurements of net soil-atmosphere exchange of CO₂, CH₄ and N₂O across a topographic and hydrological gradient. The gradient includes 30 measurement points spanning well-drained mineral soils, mineral gleysols and histosols. Measurements of ground-water depth, soil moisture and temperature over the gradient together with meteorological variables are done, too. The data from this system can resolve the little known spatiotemporal patterns and interactions of these GHGs and will be used to develop improved empirical and ecosystems models that can calculate the GHG effect of rewetting.

The SkyLine2D consists of a mobile trolley on two ropes. These are suspended between two towers. Below the trolley is a chamber programmed to be lowered on to predefined measurement points on the ground or water along the transect. The cycle is repeated three times per day. The chamber is connected to a multispecies GHG analyzer. A unique feature is that the chamber is able to land on open water, which is required as the natural groundwater fluctuations in the area result in transient drying and pooling of water on the surface of the histosols.

Controls on autotrophic and heterotrophic respiration in an ombrotrophic Bog

Northern peatlands are globally significant carbon stores, but the sink strength may vary from year-to-year. In some years, peatlands may even be carbon sources due to variations in climatic conditions. Peatlands cover roughly 12 % of Canada’s terrestrial surface, thus future changes in climate (or land use) could have an impact on Canada’s overall greenhouse gas emissions. Models can project the sensitivity of peatland carbon balance components to climate and land-use changes. However, most models partition ecosystem respiration into its autotrophic (respiration by plant parts) and heterotrophic (respiration by microbial bacteria in the soil) components using poorly known and constant ratios. This partitioning approach may lead to erroneous estimates if a change favours one form of respiration over another and alters allocations of carbon to labile pools with different turnover rates. Additionally, obtaining direct measurements is essential to explaining the temporal and spatial dynamics of respiration. The objectives of this study are thus, to partition autotrophic and heterotrophic respiration at Mer Bleue, an ombrotrophic bog, using direct methods, and to determine the factors that may influence the spatial and temporal variability in respiration. Plot level measurements will be used to partition respiration (using automatic and manual chamber methods) and will be coupled with the use of stable (δ¹³C) and radioactive (³⁷C) isotopes of carbon through end-member analysis. The role of belowground processes in peatland respiration will be also be explored, including their link to aboveground respiration. This project will improve our understanding of peatland carbon cycling as well as improve the parameterization of current peatland models.
Peatland management
Experiences from paludiculture experiments in the Netherlands: which factors influence C fixation and CH$_4$ emission?

Paludiculture is sustainable and climate-friendly biomass production on rewetted peat soils. This innovative agricultural approach can provide significant yields and simultaneously restore several important ecosystem functions. These include peat preservation, CO$_2$ reduction, water retention, water purification, and biodiversity. In the Netherlands, a lot of work has been done with regard to rewetting for climate adaptation and nature development, but also with regard to harvesting of biomass under wet conditions.

In several pilot sites and experiments, different paludiculture crops are currently investigated: cattail, reed, peat moss and willow. These pilot projects have been or will be started in co-operation with provinces, water authorities, land users, and nature management organizations. Regional economic collaborations between farmers and companies are developing.

The main objective of our research is to extend the scientific basis for paludiculture by identifying the optimal (abiotic) conditions for paludiculture crops and by quantifying the different ecosystem services in different experimental settings in the greenhouse and in the field. We will present results about the factors that influence C fixation in biomass and CH$_4$ emissions from paludiculture sites, such as water level management, top soil removal, nutrient and carbon input, specific plant characteristics, and harvest, including the life cycle of the specific biomass application. We will conclude with management options to lower CH$_4$ emissions and increase C fixation in paludiculture.

The challenges of restoring fens in Canada

In Canada, the know-how and number of fen restoration projects have been lagging behind the research done in Europe in the last decades. Nevertheless, interest to develop fen restoration techniques is increasing, especially for sites where the sedge-peat layers are exposed after peat extraction or as a mean to create a wetland after severe disturbance (oil sand extraction). In eastern Canada, a macrofossil analysis of the dynamic of fen development has confirmed the importance of re-establishing a combination of brown mosses and sedges for recovering optimal C sequestration function. Different large-scale field reintroduction experiments of fen bryophytes with the same technique used for bog restoration did not result in a successful establishment of the moss carpet. Consequently, we have started to study more closely the factors influencing the regeneration of fen true mosses. As local biodiversity hotspots, revegetation trials of pools re-created in a restored fen showed that species richness was higher for moss-revegetated pools than for the other treatments with sedges and bulrush. Also, creating pools of variable depths and introducing gram-inoid-type vegetation on their margins have also optimized the return of arthropods assemblages similar to what is observed in reference ecosystems. A vegetation study of spontaneously regenerating peatlands in central Canada has revealed that rewetting only can result in a wide diversity of vegetation patterns, with changes in soil chemistry across the site being the main driver explaining the presence of different plant communities. Nonetheless, active rewetting of fen sites is a challenge, and problems with two important large-scale projects will be discussed. In western Canada, we observe that plant reintroduction trials with different plant assemblages often converge towards Carex aquatilis dominated community.
The impacts of long term drainage and agriculture on the carbon dynamics of fen peatlands in East Anglia, UK

In the UK, fen peatlands have been drained for a variety of agricultural purposes. To date, some 1922 km² (67%) of the UK lowland fen peatlands have become severely depleted and subsequently classified as ‘wasted’ (a peatland which has lost its peat forming vegetation and significant depth of peat and is becoming more dominated by the underlying mineral layer). The East Anglian Fens have been drained significantly since the mid-19th century, and today, provide some of the most valuable and productive arable farmland in the UK. In combination, drainage and intensive agriculture have led to long-term land subsidence, primarily through peat oxidation, resulting in the loss of up to 3.9 m of the peat profile. Consequently, much of the East Anglian Fens has been classified as ‘wasted’. Recent studies on C emissions from non-wasted agricultural peatlands within the East Anglian Fens have suggested emission factors of between 5.2 to 8.3 t CO₂-C ha⁻¹ a⁻¹, indicating their significance as a component of the UK’s national greenhouse gas inventory. However, to date there has been no representative study on the emissions from agriculturally managed wasted fen peats.

Using Eddy Covariance, the CO₂ emissions of two fen peatlands co-located in the East Anglian Fens and under intensive agricultural use were quantified. One site (EF-DA) was situated on deep peat (>1 m organic layer), whilst the other (EN-SP3) was on severely depleted peat (~40 cm organic layer). An initial analysis of emissions from EN-SP3 through the 139-day maize cropping period (18th May – 2nd Oct 2018) indicated a net C balance of 1.46 t C ha⁻¹ once harvested biomass was removed. We present a comparison of the first year of data from the wasted peat site with the data collected from the deep peat site over the last ~6 years. We highlight key differences between the sites enabling us to draw early insights into how C dynamics may differ between shallow and deep lowland agricultural peatlands in the UK.

Can abandonment be a good option for restoring greenhouse sink function of drained peatlands?

Agricultural management of peatlands alters carbon gas exchanges such that sometimes, but not always, they act as “hotspots” for greenhouse gas emissions. More information is needed to clarify how management and restoration affects carbon balance of these ecosystems and their effects on the climate system. Here we measured landscape-scale carbon dioxide (CO₂) and methane (CH₄) fluxes by eddy covariance and plot-scale N₂O fluxes using static chamber technique in an undisturbed boreal bog and an adjacent abandoned peatland pasture to determine the effect of agricultural conversion and abandonment on the carbon and greenhouse gases (GHGs) fluxes. The pasture was a stronger CO₂ sink and smaller CH₄ source, accumulating a total of 167 g CO₂-C m⁻² and emitting a total of 0.37 g CH₄-C m⁻² during the two study years, when compared to the CO₂ sequestration of 17 g C m⁻² and CH₄ emission of 6.7 g CH₄-C m⁻² for the bog. Both the bog and pasture had very low growing season N₂O fluxes, accumulating -0.050 ± 0.036 g N₂O-N m⁻² in 2014 and -0.066 ± 0.193 g N₂O-N m⁻² in 2015 at the bog and -0.004 ± 0.045 g N₂O-N m⁻² in 2014 and -0.080 ± 0.199 g N₂O-N m⁻² in 2015 at the pasture. The pasture acted as a stronger carbon and GHGs sink, with a carbon balance of -167 g C m⁻² and a global warming potential (GWP) of -174 g C m⁻² during the two study years, when compared to the bog with an accumulative carbon balance of -10 g C m⁻² and a GWP of 131 g CO₂-C equivalents m⁻², respectively. Therefore, our results suggest that the carbon sequestration capacity and “climate cooling” function of agriculturally managed peatlands can become stronger than that of undisturbed peatlands after long-term abandonment. However, more studies are needed in other similar sites to verify the results on whether abandonment would be a sound restoration option for an agriculturally drained peatland.

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Can moss removal reverse undesired succession under different nutrient levels in rich fens?

Rich fens, considered as a biodiversity hotspot, particularly of brown-moss communities that form initial stages of these ecosystems and harbor a number of rare specialized species, are declining globally due to increased acidification, eutrophication (by groundwater pollution, cessation of management) and climate change that promote expansion of competitively strong *Sphagnum*. The ongoing expansion of *Sphagnum* in Europe may suppress competitively weak brown-mosses. The potential improvement may be to reverse undesired succession by removing strong competitive *Sphagnum* and initiate succession by reintroduction of target brown mosses fragments to design patches. This procedure was applied in 2015 in Bohemian Massif fens (Czech Republic) to Tatra Mts (Slovakia and Poland) on an extensive set of experimental plots in fens with different macro-nutrient availability. This experiment tests the rate and direction of succession after the *Sphagnum* removal along the fertility gradient and assesses the limits of brown moss reintroduction. We hypothesized that: (1) after the removal of dominant *Sphagnum* species, succession starts with more calcium-tolerant species; (2) in nutrient-richer fens, primary succession after *Sphagnum* removal proceeds faster and some successional stages can even miss; (3) the current occurrence of calcicole brown mosses is limited by competition with expanding calciphobe *Sphagnum* or by water chemistry. This study will evaluate the efficiency of *Sphagnum* removal as a countermeasure of ongoing undesired succession.

Legacy effects of historical land use on carbon stability in Flanders Moss’ peatlands

Peatlands comprise major but vulnerable global stocks of soil carbon. Flanders Moss National Nature Reserve in the central belt of Scotland is the remnant of one of the largest active raised bog complexes in Great Britain. Parts of this bog were drained and afforested during the 20th century while other parts remained more intact. Current management of the site intends to restore its natural structure and functions mostly by controlling water table level.

We hypothesized that as anthropogenic impact alters organic matter quality, it will make organic matter less resilient to decomposition upon temperature rise and nutrient increase. To test this hypothesis, we sampled three replicates of each above-mentioned land use and determined the temperature sensitivity of aerobic peat degradation (Q10) and influences of increasing loads of P and N using Respicond VIII apparatus. Q10 values were found to be lower in subsoil than in topsoil, thereby suggesting that with increasing age of the organic debris its decomposition sensitivity declines. Overall, the measured Q10 values of the samples increased in order drained < intact < forested bog, thus we had to refute our stated hypothesis that anthropogenic impacts on intact bogs change organic matter decomposability in a defined direction. Instead, the temperature sensitivity increased under afforestation up to an average Q10 value of 2.8. Analyses on nutrient limitation are still in progress but first data available do not show an increasing respiration under additional loads of P and N. This suggests that decomposition of the organic matter is not limited by nutrients independent of its former usage. Our initial data already indicate that there is a legacy of former land use on carbon stability that has to be considered when predicting the response of restored peatlands to global change.
Element cycling & export
Biogeochemical processes during litter decomposition/peat formation are not well understood and are studied in a complex litter bag experiment. Root litter samples were collected in three study areas (= different fen peatland types) in Northeastern Germany, each at drained (= dry) and rewetted (= wet) sites and sampling depths of 0–5, and 15–20 cm. These root litter materials have been washed, milled, placed in litter bags and buried at the same sites and sampling depths they originated from. Material from the first sampling after 6 months burial has been investigated by elemental analyses and pyrolysis-field ionization mass spectrometry (Py-FIMS). The elemental composition indicated relatively uniform reductions in C-contents (mean factor 0.9), slightly more diverse N enrichments (mean factor 1.1) and more strongly diverse alterations in S contents (factors ranging from 0.4 to 1.6). The Py-FIMS revealed phenols+lignin monomers, lipids and alkylaromatics as most abundant compound classes in almost all samples. After burial for 6 months, the chemical composition of the litter had been changed in all samples. The only general trend of organic-chemical changes across all sites was a loss in N-containing compounds, aliphatic as well as heterocyclic molecule structures. For all other compound classes there were relative enrichments at some and depletions at other sites. As a tendency, carbohydrates and phenols+lignin monomers seemed to be rather disproportionally decomposed whereas lignin dimers, lipids and suberin appeared to be enriched at most, most pronounced at the wet, sites. Lipids and suberin were also found to be enriched downwards the profiles at all sites (Negassa et al., 2019). The data set is completed by analyzing the samples after 12 months burial in soil. These first result point to an overwhelming influence of the detailed site conditions on the litter decomposition and peat formation in line with conclusions from soil profile investigations with the same methods.

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The availability of terminal electron acceptors is an important control on CO₂ and CH₄ formation in anoxic peat. In particular, CH₄ production is suppressed in presence of alternative electron acceptors, but these electron acceptors support anaerobic respiration to form CO₂. In most peat soils poor in inorganic matter, electron accepting capacities (EAC) are dominated by EAC of organic matter. Yet little is known about ranges of EAC in peat soils, and if measured changes of EAC can explain observed CO₂ and CH₄ production. Moreover, predictors for EAC of peat based on typical peat chemical properties would be needed. This would help understand CH₄ and CO₂ production in peatlands, in particular upon water table fluctuations, drought phases or flooding.

To elucidate redox properties of a range of peat materials, we collected 60 peat samples from 15 sites located in Canada, Europe, western Siberia, Patagonia, and northeast China. EAC, electron donating capacities (EDC), and electron exchange capacities (EEC = EAC + EDC) of organic matter were determined by mediated electrochemical reduction and oxidation. In addition, we quantified CO₂ and CH₄ production over 56 days at 20°C of anaerobic incubation and related CO₂ formation to observed changes in EAC. Moreover, we analysed major elemental concentrations, stable isotopic signatures, and bulk peat FTIR spectra.

EEC in the peats ranged from 668–1119 µmol e⁻ g C⁻¹. After 56 days of incubation, EAC had decreased by 178–396 µmol e⁻ g C⁻¹ and the peat became methanogenic. The observed decreases in EAC could well explain the suppression of CH₄ production and ongoing respiration to CO₂. In total, we could explain 62–91% of all CO₂ production by either CH₄ production or consumption of electron acceptor equivalents. Comparing redox properties of peat materials with peat chemical properties, however, revealed a large impact of site-specific factors and only poor relations were obtained.

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Biogeochemical processes during litter decomposition/peat formation are not well understood and are studied in a complex litter bag experiment. Root litter samples were collected in three study areas (= different fen peatland types) in Northeastern Germany, each at drained (= dry) and rewetted (= wet) sites and sampling depths of 0–5, and 15–20 cm. These root litter materials have been washed, milled, placed in litter bags and buried at the same sites and sampling depths they originated from. Material from the first sampling after 6 months burial has been investigated by elemental analyses and pyrolysis-field ionization mass spectrometry (Py-FIMS). The elemental composition indicated relatively uniform reductions in C-contents (mean factor 0.9), slightly more diverse N enrichments (mean factor 1.1) and more strongly diverse alterations in S contents (factors ranging from 0.4 to 1.6). The Py-FIMS revealed phenols+lignin monomers, lipids and alkylaromatics as most abundant compound classes in almost all samples. After burial for 6 months, the chemical composition of the litter had been changed in all samples. The only general trend of organic-chemical changes across all sites was a loss in N-containing compounds, aliphatic as well as heterocyclic molecule structures. For all other compound classes there were relative enrichments at some and depletions at other sites. As a tendency, carbohydrates and phenols+lignin monomers seemed to be rather disproportionally decomposed whereas lignin dimers, lipids and suberin appeared to be enriched at most, most pronounced at the wet, sites. Lipids and suberin were also found to be enriched downwards the profiles at all sites (Negassa et al., 2019). The data set is completed by analyzing the samples after 12 months burial in soil. These first result point to an overwhelming influence of the detailed site conditions on the litter decomposition and peat formation in line with conclusions from soil profile investigations with the same methods.
Transformation processes of phosphorus along transects in the coastal region of Northeastern Germany

Phosphorus (P) is a crucial element for living organisms in both terrestrial and aquatic ecosystems. However, excess P can cause serious environmental problems as for example eutrophication of freshwater and marine ecosystems. The potential release of sediment-based P to the water column depends on speciation, abundance and lability of the distinct P forms. In our project, we apply complementary methods as the sequential P fractionation, P K-edge X-ray absorption near edge structure (XANES) spectroscopy, $^{31}$P nuclear magnetic resonance ($^{31}$P NMR) spectroscopy and scanning electron microscopy (SEM) coupled with energy dispersive X-ray microanalyses (EDX) to obtain the best possible characterization of the P status of different transects of soils and sediments. Sample sets include sediment and soil samples along various transects through the land-wetland-water-interface in Northeastern Germany (e.g. from coastal region to the central Baltic Sea, sediment samples from the near coastal Barther Bodden extended towards the land, soil and sediment samples along a transect from an arable field into a kettle hole).

First results of these samples from diverse wet ecosystems show a decrease of the diversity of different mono- and diester-P compounds with increasing distance from the coast and higher amounts of more stable orthophosphate especially in greater water depths determined with $^{31}$P NMR spectroscopy. In accordance with all methods of this multi-methodological approach, a trend from many labile to less but more stable P compounds with decreasing terrestrial and increasing aquatic-marine impact becomes visible. The knowledge about P fluxes in the North German lowlands and coastal regions across terrestrial-aquatic boundaries can support the development of measures to reduce excess P inputs into aquatic environments, thus making a fundamental contribution to environmental protection.

Phosphorus speciation in drained and rewetted peatlands: chemical and spectroscopic analyses

The chemical and advanced spectroscopic analytical techniques such as sequential chemical fractionation, $^{31}$P solid and solution nuclear magnetic resonance (NMR), and X-ray absorption near edge structure (XANES) have been used successfully in conjunction to understand P species in mineral soils. However, we lacked similar information on peat soils subjected to different management practices. The objective of this study was to understand P chemistry in drained and rewetted peatlands using the chemical and advanced spectroscopic analyses. We collected soil samples from 0 to 80 cm depth of drained and rewetted percolation mires, alder carr forest and coastal peatlands. The total P ranged from 411 to 2072 mg kg$^{-1}$ for the drained and rewetted alder carr forest peatlands, 594 to 1447 mg kg$^{-1}$ for the drained and rewetted coastal peatlands, 495 to 2320 mg kg$^{-1}$ for the drained and rewetted percolation mires from the subsurface to surface horizons, respectively. The concentration of total P significantly decreased from the surface to the subsurface horizons by two to five folds. Results of the sequential chemical fractionation indicated the major components of the total P concentrations to be molybdenum (Mo) unreactive (MUP) and residual P. The MUP was in the range of 41 to 74 % of the total P for the alder carr forest peatlands, 46 to 73 % of the total P for the coastal peatlands, and 9 to 52 % of the total P for the percolation mires. The $^{31}$P NMR results indicated orthophosphate and orthophosphate monoesters were the predominant P species in the studied peats. The XANES analysis also revealed that Inositol Hexakisphosphate (IHP) and the IHP associated with Ca, Al and boehmite were predominant in all the peatlands. The major proportion of total P, more than 80 % of total P, existed in MUP and residual-P that indicate rewetting peatland could maintain P compounds in forms not contributing to environmental pollution.
The extent of peatlands influenced by tephra deposits from volcanic eruptions worldwide is significant, with an impact radius of tephra fall on peat accumulation of more than 1000 km observed. Interactions between tephra deposits and peatlands’ carbon dynamics are poorly understood, and more research is needed on the long-term impact of tephra deposits in these ecosystems. In Iceland, volcanic activity is among the highest in the world and might even increase due to pressure release on subglacial volcanoes. Besides tephra deposits, a potent combination of a sparse vegetation cover, low cohesion of Andosols, and frequent strong winds facilitates regular input of mineral aeolian material from eroded areas into Icelandic peatlands. Previous work provides evidence of ecosystem disturbance induced by a major tephra deposit, the Hekla 4 tephra, at a peatland at the highland fringe to an extent not observed at sites in lowland areas inland and at the coast. We present results of an ongoing study on the impact of (i) the Hekla 4 tephra and (ii) the regular addition of mineral material from eroded areas on carbon dynamics in Icelandic peatlands. Three sites in differing distance from the major erosion areas in the interior of the country and the active volcanic zones are investigated. A combination of variables is applied, including laboratory carbon mineralization at 5°C, 15°C and 25°C and carbon structure obtained by solid state 13C NMR spectroscopy. Clear between-site differences in carbon mineralization, which overall increases towards the highlands and the active volcanic zones, may only partly be explained by carbon structure. There are profound differences in carbon mineralization even from soils with conspicuously similar carbon structure. The sporadic deposition of thick tephra deposits alone seems not to disturb carbon stability, but once tephra deposits interact with regular additions of mineral material from eroded areas, equilibrium disturbance is induced.

Dissolved organic carbon in surface waters in drained and rewetted parts of a peatland in Moscow oblast, Russia

Preliminary results of a survey on concentrations of dissolved carbon in drainage flow from drained and partly rewetted peatland are presented. Water samples were taken from various parts of the drainage system. They were taken from the surface of water bodies in 100 ml bottles and an analysis was performed within 2–3 days on an Elementar – Vario TOC Cube. Measurements started in 2015. Additionally, there were conducted all-year measurements of ground water level (GWL) with automatic sensors installed in wells. According to the 2016 measurement data, a connection of dissolved organic carbon (DOC) concentrations with GWL can be detected, which indicate conditions of outflow generation. The concentrations of DOC in the ditches where additional rewetting was implemented were significantly lower than in the main channel, which accumulates water from both drained and further rewetted parts of the peatland. The DOC concentrations in Dubna river – the main water receiver from the whole peatland – were the lowest, and also followed the changes in GWL: during high-water season, concentrations were higher (up to 30 mg/l) and decreased in the low-water season (12 mg/l). In drained peatland, the case was reversed: in spring after the snowmelt GWL rise, DOC concentrations in the main channel started from 41 mg/l, but in the middle of summer when GWLs were low, DOC concentrations were much higher (95 mg/l). The study was partly supported by the project “Restoring Peatlands in Russia – for fire prevention and climate change mitigation”.

Tephra deposits in peatlands – a neglected impact factor of carbon dynamics?

The study was partly supported by the project “Restoring Peatlands in Russia – for fire prevention and climate change mitigation”.
Abstracts of Poster Presentations
Nitrous oxide emissions of rewetted, agriculturally used temperate peatlands

In drained peatlands, peat is mineralized and degraded among others to the greenhouse gas nitrous oxide (N\textsubscript{2}O), which may be further reduced to dinitrogen (N\textsubscript{2}). One option for reducing mineralization and production of N\textsubscript{2}O is to restore peatlands by rewetting. However, this often leads to the loss of agricultural land. Here, paludiculture, i.e. the agricultural use of rewetted peatlands, might be an option.

However, the dynamics of the formation of N\textsubscript{2}O and N\textsubscript{2} has not been well studied on organic soils, and so far not at all on rewetted, agriculturally used peatlands. Therefore, we analyzed N\textsubscript{2}O emissions on drained as well as on neighboring rewetted, agriculturally used sites in North-Eastern Germany. In order to reduce N\textsubscript{2}O emissions, it is important to understand the different biochemical production pathways by which it is produced. To distinguish among the microbial production pathways nitrification, nitrifier denitrification and denitrification, we used the dual-isotope method with four different tracers (\textsuperscript{15}N-N\textsubscript{H}\textsubscript{4}, \textsuperscript{15}N-N\textsubscript{O\textsubscript{3}}, \textsuperscript{18}O-N\textsubscript{O\textsubscript{3}} and \textsuperscript{18}O-H\textsubscript{2}O). A better process understanding of the sources and sinks enables more targeted management for reducing N\textsubscript{2}O emissions in these systems. First results of the measurements will be presented.

Non-proportionality between anoxic CO\textsubscript{2} fluxes and soil organic carbon mass

We designed a simple and robust experiment to determine if CO\textsubscript{2} (and CH\textsubscript{4}) fluxes derived from soil heterotrophic respiration were proportional to soil organic carbon mass under oxic and anoxic conditions. Surface peat collected from a peatland underlain with permafrost was thoroughly homogenized and used to fill columns (25 cm inner diameter) 30, 50 and 100 cm high, with peat mass being proportional to column height. CO\textsubscript{2} fluxes under oxic conditions measured during the first week were proportional to soil organic carbon mass (R\textsuperscript{2}=0.98), as expected. Soil columns were then slowly filled with peat porewater to provide for >200 days complete water saturated and anoxic conditions. CO\textsubscript{2} fluxes measured under water saturated conditions throughout the experimental period were clearly not proportional to peat mass (R\textsuperscript{2}=0.01).

This non-proportionality has strong implications for gas emissions modelling in waterlogged ecosystems since models typically assume that CO\textsubscript{2} flux increases with soil depth due to incremental heterotrophic respiration upon addition of soil layers, an assumption we provide evidence against.

Atmospheric carbon fluxes of a formerly drained fen up to 14 years after rewetting

Degraded peatlands constitute significant and long-term carbon dioxide sources and thus contribute to climate warming. In the northeastern German state of Mecklenburg-Western Pomerania, an estimated 20 – 30 % of the statewide carbon dioxide (CO\textsubscript{2}) emissions are attributed to drained peatlands and one strategy to reduce national greenhouse gas emissions is therefore the re-wetting of peatlands to restore their natural carbon sink capacity. However, the long-term development of carbon fluxes of rewetted fens is highly site-specific and uncertainty remains with regard to if and when such sites turn into carbon sinks.

Surface-atmosphere fluxes of CO\textsubscript{2} and CH\textsubscript{4} were measured at "Polder Zarnekow" (Fluxnet ID: DE-Zrzk), a formerly drained and rewetted rich fen located in the Peene River valley. Draining the fen began in the 18th century and was intensified between 1 960 and 1990, when the water table was lowered to > 1 m below the surface. Mineralization of the peat caused the surface to subside to levels below the adjoining Peene River. The site was rewetted by inundation during the winter of 2004/05. A shallow lake with a fluctuating water table of up to 1.2 m depth and an area of about 7 ha developed. A layer of organic sediment formed at the bottom of the lake, originating from the fen’s former vegetation. It has since been annually replenished by dying aquatic plants and helophytes.

A first observation period covers the years 2007 – 2009. Continuous monitoring has been ongoing since 2013. Preliminary results suggest that methane emissions are remaining high (28 – 39 g m\textsuperscript{-2} yr\textsuperscript{-1}) while CO\textsubscript{2} effluxes show a declining trend eventually turning the site from a CO\textsubscript{2} source to a CO\textsubscript{2} sink in 2018.

We present a time series of surface-atmosphere carbon fluxes and annual carbon balances (excluding lateral transport) from 2014 to 2018. Drivers of the turbulent fluxes are analyzed on various time scales and the role of observed temporary summertime drying of the lake in the net carbon balance is analyzed.
Abstracts of Poster Presentations

Heat wave 2018 – Impact on Rzecin peatland carbon balance in the context of the optical parameters of the atmosphere

Peatlands are one of the biggest reservoirs of organic carbon in the biosphere that are very sensitive to climate conditions. Therefore, wide research of the interaction between these ecosystems and the physical properties of the atmosphere (e.g. thermics, optics and humidity) is crucial for understanding and predicting their functioning in the future. However, the effectiveness of CO2 exchange between peatlands and the atmosphere depends also on the physiological status of plants. 2018 was in Poland a hot and dry year and these conditions impacted many ecosystems including peatlands.

The main goal of this study was the assessment of Rzecin peatland reaction to the heat wave period in 2018. Both thermal/humidity and optical conditions were considered during this analysis to take account of the complex character of peatland-atmosphere interaction.

The data was collected at Rzecin peatland (52°45’N, 16°18’E). The standard micrometeorological measurements were carried out during 2018 and were supplemented with additional sensors e.g. CE318 sun photometer (CIMEL Electronique, France), Bistatic Radar System for Atmospheric Studies (BASTA) and ESA Mobile Raman Lidar (EMORAL). These additional sensors were used in order to study the optical parameters of the atmosphere. All these activities were done in the framework of the Technical assistance for Polish Radar and Lidar Mobile Observation System (POLIMOS). The initial results show sensitivity to hot/dry atmospheric conditions but also to optical parameters of the atmosphere.

Effects of submerged drains and ditch blocking on GHG emissions from intensive grassland on fen peat

Drainage is a prerequisite to use peatlands as grassland, but this practice causes high emissions of greenhouse gases (GHG). The project ‘SWAMPS’ focuses on both maintaining the trafficibility for intensive grassland use and the reduction of GHG emissions by managing the groundwater level. Here, we aim to evaluate the effect of water table management on the emissions of CO2, N2O and CH4 over two years.

We set up an experimental site at a grassland on fen peat in North-Western Germany. The water management includes submerged drains, blocked ditches and a drained control site. Diurnal CO2 flux measurement campaigns are realised once every three to four weeks with transparent and opaque chambers. CH4 and N2O samples are taken biweekly and additionally more frequently after fertilization.

Due to constraints in the water management, there were only slight differences in water level during summer 2017. During the extremely dry summer 2018, however, water levels were raised by > 30 cm by the submerged drains, while the site with blocked ditches was undistinguishable from the control site (around -65 cm). In 2017, all treatments exhibited typical GHG budgets for shallow-drained, nutrient-rich grassland (24-40 t CO2-eq ha⁻¹ yr⁻¹). Surprisingly, during the first year, CO2 emissions were notably lower at the treatments with submerged drains and blocked ditches, respectively. N2O emissions ranged from 1.6 to 4.4 kg N ha⁻¹ yr⁻¹ and were in 2017 slightly lower at the water treatment parcels, while the site with submerged drains showed higher N2O fluxes in 2018. CH4 fluxes were negligible on all water treatments.

However, the GHG balances of the first year (2017) reflect a transition period between antecedent and experimental conditions and are not representative for a fully operational water management system. Complete results from 2018 will be presented as well, and measurements will be continued for another two years to clarify the effects of water management on GHG emissions.
Drainage and conversion of tropical peat swamp forests (PSF) into agricultural systems alters the greenhouse gas (GHG) balance of these ecosystems and accelerates oxidation of accumulated organic matter. Under natural conditions, PSFs accumulate carbon (C) in tree biomass and as partially decomposed plant material in the soil. In addition, these waterlogged soils release large amounts of CH$_4$. After drainage, oxidation of the organic matter increases, increasing soil CO$_2$ emissions and decreasing CH$_4$ emissions. Although a number of studies have studied the GHG emissions on drained tropical peatlands, most of this research has focused in large-scale plantations (mainly oil palm) and GHG emissions from smallholder agricultural systems (SHA) have received little attention. In this study, GHG fluxes from SHA systems were investigated at four locations across South East Asia. At each location, three study sites were established in each of four land-use classes. Land-use classes were defined according to local conditions but fell into four broad categories: annual vegetable crops (winter melon, pineapple, turmeric, ginger, water spinach); tree crops (banana, rubber, jelutung); oil palm (recently planted, 3–4 years, 8–9 years and 13–15 years old); and peat swamp forest. In total, 48 instrumented research sites were established across Malaysia and Indonesia. At each study site, monthly GHG fluxes were measured in the presence and absence of root processes via a trenching experiment, at locations close to and distant from the crop, using a closed chamber system. Gas samples taken in the field were analysed by gas chromatography. Additional measurements for CO$_2$ and CH$_4$ were made in situ using Los Gatos CO$_2$/CH$_4$ analyser. Initial results suggest cultivated peat sites are a consistent and significant source of CO$_2$ emissions and a sporadic but periodically large source of N$_2$O emissions. High emissions of CH$_4$ were largely confined to wetter forest sites.

Greenhouse gas emissions from smallholder agricultural systems in drained tropical peatlands in South East Asia

Poster no. T1-08

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Methane (CH$_4$) and nitrous oxide (N$_2$O) emissions were determined using an opaque closed chamber method along water level gradients from littoral zones of constructed shallow lakes with different vegetation zones in a nutrient-rich cutover peatland in Sweden. CH$_4$ emissions from the vegetation-free constructed shallow lake were low during all water level conditions and over the temperature ranges observed and were highest from *Thypha latifolia*, followed by *Carex* spp. and communities of both. N$_2$O emissions contributed little to the GHG fluxes from the soil-plant-water systems to the atmosphere, despite the C:N ratio in peat being below 25. Rewetted peatlands are sensitive ecosystems and they can act as GHG sinks or GHG sources due to small changes in hydrology, vegetation cover and weather conditions. 28 years after rewetting, it is still unclear if sites are net GHG emitters or if a C sink function has recovered. Shore zones can be hot spots for CH$_4$ but peat-forming and other wetland plants have established and terrestrialised the shallow lakes for a prospective C sink.

Rewetting of extracted peatlands in Sweden: experiences from restoration and monitoring of greenhouse gases

Poster no. T1-07

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Spruce forest on drained peat – clear-cut winter 2019, half replanted and half rewetted into meadow

We have used the CoupModel to investigate effects on GHG emissions as well as on economy of 80 years of peatland use for four scenarios (1) business as usual – Norway spruce with average soil water table depth (WTD) of -40 cm; (2) willow plantation with WTD at -20 cm; (3) reed canary grass production with WTD at -10 cm; and (4) a fully rewetted peatland with no harvested product. Total soil GHG emissions for the scenarios were (including litter and peat respiration CO₂ emissions as well as N₂O and CH₄) on average 33, 19, 15, and 11 Mg CO₂ eq ha⁻¹ yr⁻¹. No peat was lost for the wet peatland. GHG emissions were at a minimum at WTD -10 cm. Economy was analyzed by a cost – benefit analysis (CBA) where scenario (1) with spruce included gain from sold products like timber, pulpwood and energy biomass, and scenarios (2) and (3) gains from energy biomass. Gains over the 80 years resulted also from stored C in biomass and litter as well as biodiversity for scenario (4). Costs included management and soil emissions. The CBA showed on average the best result for the rewetted peatland (4) while spruce (1) production’s economic benefit was the lowest.

We are now about to clear-cut the mature spruce forest at Skogaryd research station, on which the model was calibrated. Half the area will then still be drained and planted with spruce and the other half rewetted to a wet meadow by building a dam. Collection of ecosystem and flux data has been extensive for more than a decennia and will continue.

Researchers are invited for investigations following the changes taking place after the clear cut. We will present projected losses to air and water estimated by the CoupModel.

Canopy metrics to describe vegetation dynamics and their effect on CO₂ exchange in pristine and rewetted peatlands

Vegetation dynamics are in the scope of many restoration studies and essential for the peatland C cycle. Plant phenology and succession can be quantitatively described with canopy metrics derived from digital repeat photography or satellite imagery. Although such data can be easily obtained, only few studies have incorporated canopy metrics to investigate the peatland C cycle. Here, we give an overview of application fields for canopy metrics with examples spanning from continental-scale network studies down to plot-scale field trials.

Continuous time series of canopy greenness derived from digital repeat photography can be used to parameterize the functional effect of phenology on peatland CO₂ exchange. We will present a model approach developed within the European PhenPeatCam network that constrains phenological effects on the gross ecosystem productivity of peatlands and also accounts for existing interdependencies with abiotic controls. Incorporating such biotic-abiotic linkages into empirical models can advance our mechanistic understanding of the peatland C cycle.

Further, vegetation succession is in the focus of many peatland restoration projects and tightly linked with photosynthetic CO₂ uptake and peat formation. We will report on using satellite-derived vegetation indices to describe the shifts in vegetation and phenological timing that occurred after flooding of a minerotrophic fen. The observed vegetation dynamics were well related to the interannual variation in peatland CO₂ exchange. Finally, we will discuss ongoing research on the deployment of digital repeat photography in restoration experiments. Here, RGB image archives can be used to parameterize plant colonization on plot scale and thereby improve predictive CO₂ exchange models.
CO$_2$ and CH$_4$ dynamics of a restored fen after in-situ well site disturbances

In the oil sands region of Alberta (CA), a vast area of peatlands is disturbed by the in-situ oil and gas mining activities via construction of mining platforms (> 1 ha each) and associated infrastructure, such as access roads, exploratory well pads, and processing plant facilities. These disturbances result in the regional peatlands to face the loss of biodiversity, changes in hydrology and chemistry attended by the introduction of different soil material and alien species, and most importantly their C sink function. Operating companies have to restore the disturbed sites to an “equivalent land capability”, with a main objective to return hydrology and plant communities that will reinstate the C sequestration function. Only few studies have yet been undertaken to restore fen ecosystems on the mineral soil of the former in-situ well pads.

Restoration techniques for two well pads in the Peace River and Cold Lake oil sands included the partial and complete removal of the mineral soil. The objectives of the study were to evaluate C fluxes from restored area and compare these values to reference peatlands. CO$_2$ and CH$_4$ fluxes were measured on the main vegetation communities that established on former well pads and hummocks and hollows in regional reference ecosystems during two summer seasons. We observed that in areas of complete mineral soil removal, shallow open water sections formed, favoring high CH$_4$ emissions. Furthermore, spontaneous vegetation consisted of communities with dominant Typha latifolia. To the contrary of our expectations that the original well pad is not suitable for wetland establishment, we here found a variety of brown mosses which contribute to the CO$_2$-uptake and may have a positive effect on the greenhouse gas balance. In conclusion, the restoration of in-situ well pads can result in surprising soil-vegetation-interactions that affect the greenhouse gas cycle to an extent that needs to be further examined and monitored.

Is it possible to cultivate peatlands climate- and environment-friendly?

Peatlands are actively drained and cultivated especially in Northern Europe. In Finland, peatlands comprise one third of the total land area while over half of these are drained. Cultivated peatlands (about 10% of total field area) are regionally important for fodder crop production. Agriculture comprises one of the biggest sources of anthropogenic greenhouse gas (GHG) emissions and cultivated peatlands may have especially high emissions of carbon dioxide and nitrous oxide. In addition to high GHG emissions, cultivated peatlands may cause high nutrient and organic carbon loading to waterways. We study the effects of peatland cultivation on both GHG emissions and water run-off quality in Ruukki study site in Northern Finland. The site is operated by the Finnish Natural Resources Institute (LUKE). The total area of the field is 19.5 ha and the peat depth varies between 30 and 70 cm. The field is divided into 6 different sections, where the water table, soil moisture, leaching of water and its quality can be monitored. We combine detailed hydrological analysis and modelling, soil analysis with GHG measurements and utilize latest measurement technologies to study the climatic and environmental effects of peat depth and different moisture conditions as well as various crop rotations and cultivation techniques in production of feed crops at cultivated peatland.

The study is part of the international PEATWISE-project (Wise use of drained peatlands in a bio-based economy: development of improved assessment practices and sustainable techniques for mitigation of greenhouse gases) funded by FACCE ERA-GAS.
Paludiculture could combine ecological and economic goals in degraded peatland ecosystems. Here, we evaluate the attempt of commercial Sphagnum farming on former peat extraction sites in northwestern Germany, which are, in contrast to previous Sphagnum farming experiments, characterized by strongly decomposed “black” peat. Over a period of two years, we monitored the development of bryophyte and vascular vegetation and measured the exchange of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) using manual chambers. Experimental sites were a near-natural bog, an irrigation polder and two cultivation sites. One cultivation site was established with both drip and ditch irrigation directly after terminating the peat extraction, while the other one had been rewetted as a shallow polder for seven years before lowering the water table to enable Sphagnum growth.

Water management had a strong impact on groundwater levels, Sphagnum growth and thus on the greenhouse gas exchange. Previous rewetting seemed to improve the soil hydrological conditions, while drip irrigation provided more favorable conditions during the initial phase of Sphagnum farming than ditch irrigation. Despite all efforts, the extraordinary hot and dry summer of 2018 resulted in low water levels and a stagnation of Sphagnum growth. Due to the slow development of the peat mosses during the establishment phase and due to temporary droughts, most sites were still net sources of CO₂. Surprisingly, CH₄ emissions of the near-natural site were higher than those of the irrigation polder, while fluxes from the cultivation sites were small. N₂O emissions from the two cultivation sites were higher than expected, especially after a dry period at the ditch irrigation site. Probably, the low vegetation cover at this site resulted in negligible nitrogen uptake. Passive warming of selected plots by Open Top Chambers slightly increased air and soil temperature, which led to higher emissions of all three gases.

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## Paludiculture

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- Passive warming of selected plots by Open Top Chambers slightly increased air and soil temperature, which led to higher emissions of all three gases.

## Long-term high-resolution lander for determination of trace gases, nutrients and marine parameters in flat coastal water

Atmospheric methane (CH₄) and carbon dioxide (CO₂) concentrations have risen since 1750 by about 150% and 40%, respectively, considerably contributing to climate change. Marine CH₄ emissions are often enhanced in shelf regions with respect to the open sea and it is suggested that shallow waters are an underestimated methane source. Quantification of fluxes from the shallow coast is hindered by the high temporal variability in governing parameters such as currents, temporal stratification, and lateral sediment transport.

Within the DFG Research Training Group Baltic TRANS-COAST, we investigate the dynamics of nutrient and trace gas fluxes in the nature reserve “Hütelmoor & Heiligensee”, a re-wetted low-lying peat site, and the adjacent shallow coastal areas. To face the challenge of high temporal variability on the coastal side, we developed a benthic lander system with a wide analytical tool box for serval in situ determinations. The lander continuously records temperature, salinity, oxygen, turbidity, and chlorophyll a. An optical nitrate and a wet-chemical phosphate sensor are integrated, and in addition, the system carries CH₄ and CO₂ sensors, which are based on absorption spectroscopy in the IR-range. Power supply is provided by a central battery pack (single-use or rechargeable). Sensor control and data retrieval is achieved by a central data processing unit (DPU) with an internal logger system. The system is developed for shallow water bodies (1-15 m) and can thus be deployed on wetlands and shallow coastal sites alike.

We plan the first deployment of the system in summer 2019 in shallow water bodies to get the first field data from all sensors. We expect the new lander system to show considerable advantages in the assessment of the high spatio-temporal variability of trace gas production compared to traditional sampling schemes.
Peatland ecosystems cover only 3% of the Earth’s land surface but store up to 30% of the global carbon (C) pool. As long as they are undisturbed, they act as major, long-term C sinks. However, almost 60% of peatlands in Europe have been drained for the purposes of peat extraction and agricultural use. The drainage and the input of nutrients such as nitrogen disturb the C dynamics and may turn these ecosystems to strong sources of greenhouse gases. Today, many peatlands are restored, and rewetting is one of the measures. One of the goals is to regain the peatlands’ potential to act as C sinks and thus to contribute to global warming mitigation.

The “Uchter Moor” in NW Germany (52° 30’ N, 8° 49’ E) is a raised bog and part of the “Diepholzer Moorniederung”. It is a rather specific site in NW Germany, because it has been drained for peat extraction, but never been used as farmland. It is therefore an oligotrophic bog. The actual site, within the peatland, remained undisturbed until 60–70 years ago. Afterwards, peat has been cut until the year 2000, when rewetting began. In 2016, 16 years after rewetting, an eddy covariance setup was established to monitor the flux of the five most important greenhouse gases H₂O, CO₂, CH₄, N₂O and O₃, over an 18-months period. We show the results as well as the annual greenhouse gases’ balance and its implications on the global warming potential of the site, 16 years after rewetting.

Chamber-based gas flux measurements have commonly been used as a basis for quantifying ecosystem CO₂ uptake and emissions for many decades. Yet the data processing pipeline from raw data to ecosystem balance is not as highly standardised for this method as it is for the eddy covariance technique that has only become widespread since the 1990s. This circumstance limits the intercomparability of results from studies conducted with dynamic flow-through chambers. CO₂ budgets can for example be determined from chamber-based flux measurements using the freely available software environment R. Both a user-submitted extension package called flux as well as an R script accessible on the internet (Hoffmann et al. 2014) are available to calculate flux rates and model ecosystem respiration and gross primary production. Disclosing parameter settings and making raw data available should enable scientists to reproduce ecosystem CO₂ balances estimated with either. However, a question mark remains regarding the intercomparability of the respective results. Differences in flux and/or model selection can bring about diverging CO₂ budgets. Additionally, neither of the two applies the exact flux selection criteria as the expert-based CO₂ balancing approach used in research projects carried out before the advent of automated data analysis. Hence, comparison with those results is problematic as well. We thus attempted to make data processing as similar to our former manual practice as possible. As the R script resembles a black-box approach and is not very user-friendly, we chose to implement our protocol by expanding on the flux R package. Adjustments made pertain to flux selection for the most part. We compared the results obtained from this solution with the two existing R-based methods, and also tried to quantify the effect of choosing different ecosystem respiration models including such that take groundwater level into account.
Drainage ditches in peatlands seem to be “hotspots” of methane (CH₄) emissions. The aim of this investigation was to find out how these emissions differ depending on the land use, how they are influenced by further ditch properties and how big the impact of ditches is on the CH₄ exchange. The CH₄ emissions of two ditches in the two percolation peatlands of the WETSCAPES project in Mecklenburg-Western Pomerania were examined. One of the peatlands was rewetted 20 years ago while the other one is still drained and used as grassland. The diffusive exchange was measured with the floating-chamber method and bubble traps were installed to measure the emissions via ebullition. Further field parameters were recorded and water and substrate samples taken. The measurements were made biweekly from May to September 2018. That summer was exceptionally hot and dry.

The CH₄ emissions from the ditches differed significantly depending on land use: the emissions of the rewetted site were much higher (245.26 (± 426.5) mg CH₄ m⁻² h⁻¹) than the ones from the drained grassland (31.67 (± 60.2) mg CH₄ m⁻² h⁻¹). Additionally, there were significant differences within the investigation areas regarding the orientation of the ditches, with the ditches with standing water having much larger emissions. In every ditch, the diffusive emissions took the main part of total emissions (> 85 %). Even though the area covered by ditches is small (< 3.4 %), the emissions have a relevant impact on total CH₄ emissions of the investigation areas. The explaining variables in the created model were air temperature, redox potential, ammonia-N and DOC-content; they explained 63 % of the variation in emissions. Besides, there seems to be a big impact of ditch condition and vegetation.

Peatlands store large amounts of terrestrial carbon and any changes to their carbon balance could cause large changes in the greenhouse gas balance of the Earth’s atmosphere. There is still much uncertainty about how the dynamics of peatlands are affected by climate and land use change. Current field-based methods of estimating annual carbon exchange between peatlands and the atmosphere include flux chambers and eddy covariance towers. However, remote sensing has several advantages over these traditional approaches in terms of cost and spatial coverage. In this study, we produced a time series from 1998 to 2016 consisting of annual gross and net primary productivity using the satellite-based Biosphere Energy Transfer Hydrology (BETHY/DLR) model for the entire federal state Mecklenburg-Western Pomerania (MV, Germany). All landscape types except peatlands were excluded and the remaining pixels were ordered by their main peatland type. The four main types were percolation peatlands (41 %), terrestrialization peatlands (28 %), flood peatlands (14 %), and paludification peatlands (13 %). All together, they cover 95 % of the area of peatlands in Mecklenburg-Western Pomerania. Regarding gross primary productivity, the results show significant differences between these four peatland types. Percolation mires and paludification mires have the highest amount of carbon sequestration followed by the terrestrialization peatlands. Flood peatlands (including coastal and floodplain peatlands) seemed to sequester much lower amounts of carbon. A certain shape within the time series, which is clearly recognizable in all four peatland types, was compared to climate parameters. Preliminary results were also produced considering the different grades of drainage (not, moderately, strongly and extremely drained) for all types but these results have to be interpreted very carefully since rewetting processes started in some cases during the period between 1998 and 2016.
Using a calibrated land subsidence model and GIS for developing water management scenarios in peatlands

Mires are globally relevant carbon stores, possess important water regulation properties and create habitat for rare species of plants and animals. However, most mires in north-eastern Germany have been drained in order to make the areas available for agriculture, entailing land subsidence, peatland loss and greenhouse gas emissions. In the present study, land subsidence and peatland soil degradation were investigated in the Havelländisches Luch, a drained lowland mire in north-eastern Germany. The goal of this study was to assess the potential of water table adjustment for diminishing these negative effects in the future and enabling sustainable land use. To this end, land subsidence was modelled for the past five decades by using a differential equation reflecting peat mineralization in dependence of peat layer thickness and groundwater level. Different water management scenarios representing water table adjustment and climate change were developed based on the calibrated subsidence model and calculated for the year 2040. Scenario-specific future terrain models, groundwater models and peat layer thickness maps were analyzed in ArcGIS in order to create scenario-specific visualizations. The resulting scenario maps were used to communicate implications, advantages and expected challenges to local stakeholders. With increasing availability of up-to-date LiDAR-derived digital elevation models (DEMs), the combination of a relatively simple groundwater-dependent land subsidence model and GIS tools would be a practical methodological option for environmental planners analyzing possible outcomes of peatland rewetting projects. However, the latest available LiDAR-derived DEM1, which was used in this study to determine current elevation values, was found to include considerable imprecisions, consistently over-estimating ground elevation with up to ca. 30 cm on unmown grassland. Finding technically straight-forward solutions for removing such errors will be vital in ensuring the practicality of this scenario development approach.

Spatial valuing ecosystem services on tropical peat community forest

When it ratified the Kyoto Protocol, Indonesia agreed to reduce carbon emissions by managing its forest and peatlands. In Riau Province, 5.3 million hectares of tropical peatland ecosystems are spread along the eastern coast including the islands on the Malaka Strait. Land use changes on Tebing Tinggi Island caused deforestation on 74% of coastal peatlands. Assignment of HPH (Natural Forest Management Permit) and HTI (Industrial Plantation Forest) involved accelerated deforestation and drainage. Awareness of increased rates of deforestation came not only to the government but also to local communities (in which the NGO WALHI was instrumental) long before the massive peatland fires in 2014. In 2016, seven villages earned 9,960 ha of communal forest where HTI of the company PT LUM were located. The belowground carbon store and the 7,700 ha of forestry needed to be conserved. Zonation of this tropical peat ecosystem is based on regulatory ecosystem services provided. Provisional services are central on 447 ha of sago plantations. This agro-ecosystem is the major community-based commodity, along with potential eco-tourism. These services are supported by the government. LiDAR and aerial photos are the primary source of spatial data for mapping and valuing ecosystem services inside the communal forest. The participatory mapping by local forest community holders accelerates the process of defining assets and helps raise awareness for protecting the forest. The practice of paludiculture (including non-timber forest products) on the communal forest could reduce deforestation from logging and support the sago plantation through steady provision of water resources by the peat dome.
In recent years, large scale peatland restoration has been carried out in the Tver region in the framework of the project “Restoring Peatlands in Russia – for fire prevention and climate change mitigation”. One of the most important performance indicators of the restoration process is the change of surface vegetation. Due to the large size and inaccessibility of most sites, it is difficult to ascertain the scale of restoration and its success. During summer and autumn 2017, we studied Orshinsky Mokh, where natural revegetation of milled peat extraction fields and partial self-re-wetting can be observed. For a detailed assessment on vegetation, we selected two plots of 100 × 100 m. We used a DJI Phantom 4 Pro drone with Drone Deploy software to create the route of survey and Agisoft Photoscan software for data processing. Surveys were conducted with maximum flight altitudes of 50 and 100 meters, a maximum velocity of 5 – 7 m/s, a forward shots overlap of 75 %, and a lateral overlap of 80 %. For each of the two plots, we thus obtained orthophotomaps and digital terrain models in two levels of detail. The vegetation of the plots was described on the basis of the orthophotomaps (with a respective resolution of 2.6 – 2.8 cm/px and 1 cm/px) and on field surveys and includes reedgrass associations with birch and willow, where grasses cover 20 % to 70 %. In humid parts, mesophytic and hydrophylic grasses are found. Moss species composition is poor, with prevailing Polytrichum commune. A 3D model of the area was prepared, clearly showing drainage ditches and roads, but also providing a means to estimate the relative elevation of bare (black) peat areas, as well as of grasses, shrubs and trees.
Bryophytes’ productivity and decomposition in fens along the environmental gradients

The functioning of fen ecosystems is highly dependent on bryophytes, which belong to the most important peat-forming plants. Peat formation occurs when production exceeds decomposition. Bryophytes’ production and decomposition are dependent on many factors such as nutrient availability and water level. It is also dependent on bryophyte species composition of the site. The moss decomposition and production was studied in Biebrza and Rospuda mires along a trophic gradient. We have chosen moss species that dominate the study sites and are assumed to have a significant contribution to peat formation: Aulacomnium palustre, Brachythecium rutabulum, Calliergonella cuspidata, Calliergon giganteum, Campylium stellatum, Climacium dendroides, Drepanocladus aduncus, Fissidens adianthoides, Hamatocaulis vernicosus, Limprichtia cossonii, Tomentypnum nitens.

Moss mass loss was studied using litter bags and moss production was studied using the plug method – growth was measured on moss shoots collected from patch, cut to 4.5 cm apical lengths, weighted, placed into a steel basket and carefully replaced into the moss patch. Average moss mass loss after one year of incubation in peat was 26 % (SD = 7 %). The maximum weight loss recorded was 49 % and the minimum 9 %. Average production was 203 g m⁻² yr⁻¹. These values were different for mosses forming hummocks and for mosses occurring in hollows. There was a significant effect of environmental factors such as water level amplitude, aboveground vascular plant production and pH on moss production and decomposition rate.

Patterns and drivers in spring and autumn phenology differ above- and belowground

Start and end of the growing season determine a shift from a carbon sink over summer to a carbon source over winter in temperate and colder ecosystems. Drivers of plant phenology may differ above- and belowground, between autumn and spring, as well as among different plant communities. Root phenology, in particular, is ecologically relevant but understudied. In this study, we compare above- and belowground spring and autumn phenology, as well as their abiotic drivers in four typical temperate plant communities of Central Europe. We measured root growth in-situ with minirhizotrons in beech forest, alder carr, Typha-reed and Carex-reed along with abiotic parameters (temperature, water level and soil moisture). Dendrometer data and NDVI measurements characterized the aboveground season.

Asynchrony in the timing of above- and belowground phenology was found dependent on plant community. Onset of root growth, as compared to shoot growth, was delayed in all three peatlands, but not in the beech forest. The growing season ended earlier belowground than aboveground in the two forested plant communities, while no difference was detected for the Typha-reed. In all plant communities, fine root production increased over the growing season as soil temperature increased and, in the peatlands, water level decreased. Root production in the alder carr was not correlated with water level in spring but decreased significantly with water levels rising in autumn. In the beech forest, abiotic factors were less correlated with leaf activity or root production. The peatlands, however, were less correlated with temperature in autumn, but strongly correlated with water level through all seasons.

We show that plant communities under the same macroclimatic conditions can differ significantly in the start and end of their growing season. A distinction between above- and belowground phenology is indispensable, since overall plant phenology cannot be drawn from aboveground phenology alone.
The mire area is decreasing with a growing demand for peat as a major constituent of most horticulture growing media. To restrict the decrease, the destroyed area can be restored with peat moss. The peat moss biomass is a new sustainable alternative for horticultural media with similar chemical and physical properties to peat. The main limitation for large-scale Sphagnum farming is the necessary seed-biomass. To establish a system to produce the sufficient amount of peat moss biomass, we have designed a scale-down of a photo-bioreactor (PBR) to laboratory-scale. The PBR steam-sterilizable prototype was built with a surface area of 100 cm$^2$ (cultivation volume 1.5 L) with a continuous light supply from white LEDs, emitted in the entire photosynthetically active radiation. Continuous gas supply is with carbon dioxide concentration ranging from 0 – 10 % in the air. By homogenous spraying, the medium is supplied intermittent to the culture, with adjustable frequency.

Two cultivation systems with *Sphagnum palustre* under photoautotrophic condition were examined: one with the biomass positioned on the stainless steel grid, and one with PP-mats, used for a field study. The biomass yield under cultivation in emersed conditions by around 1-fold in 5 weeks (0.57 g m$^{-2}$ d$^{-1}$) does not exceed literature data from heteroautotrophic submerged cultivation (10- to 30-fold within 4 weeks), but is higher than under natural condition. In both cases, the leaf color changed from green to yellow. This suggests that the physiological state of peat moss is more influenced in the tested emersed cultivation system than in a submersion reactor. For this reason, currently, several reactors are being operated to determine the cultivation parameters influencing *Sphagnum* growth.

Development of a photo-bioreactor for large-scale mass production of peat moss

Poster no. T3-05

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.miscanthus* x giganteus* is a highly productive energy plant with C4 photosynthetic pathway, which can be cropped also on marginal sites. Its high productivity and a dense rhizome network suggest a high carbon sequestration potential, but results on soil carbon stock effects are contradicting. Even though an increase in the soil bulk $\delta^{13}C$ signature is always observed, the effect of Miscanthus on net soil C sequestration seems to depend mostly on the previous land-use, under similar climatic conditions. Earlier studies, carried out on mineral soil, indicated that Miscanthus fields tend to accumulate SOC after conversion from cropland. Here, we report on a sequence of five paired sites in close vicinity to each other comprising a topsoil SOC gradient from 60 – 286 t ha$^{-1}$ (0 – 30 cm) (corresponding to 1.3 – 17.9 % SOC). Miscanthus was cropped for 19 – 24 years, preceded by cropland, and C stocks and isotopic signatures were compared to the control sites without *Miscanthus*. We hypothesized net SOC accumulation and that accumulation of C4-C (as recorded in $\delta^{13}C$ of bulk soil carbon) should be higher on sites with lower SOC content because of stabilization mechanisms of the mineral matrix. We find that Miscanthus cropping did not lead to a net SOC increase, but an annual accumulation of C4-C of between 1.0 and 2.7 t C ha$^{-1}$ in 0 – 30 cm. The $\delta^{13}C$ signatures of SOC approached values of reference sites below that depth. Annual accumulation rates were positively and significantly related to SOC content, indicating that organic soils provide better conditions for accrual of new C. Possible mechanisms for this will be discussed.

Accumulation of soil carbon under *Miscanthus* in organic soils

Poster no. T3-04

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Peatlands are a type of ecosystem with relatively low net productivity but a very long-term storage period (thousands of years). They play a very important role in the global carbon cycle since they store one-third of global soil carbon while they cover only 3% of the land area. The hydrogenic origin of these ecosystems results in their high sensitivity to climate parameters such as temperature and precipitation. A shift in thermal and hydrologic conditions can change the peatland from net absorbers to emitters of CO₂ to the atmosphere. Thus, peatland-climate interaction studies are crucial for their understanding and prediction of their future fate. Long-term measurements of heat and mass exchange between peatland and atmosphere have been carried out at Rzecin peatland, Poland (52°45'N, 16°18'E, 54 m a.s.l.) since 2004 and the eddy covariance technique is applied for the monitoring of CO₂/H₂O net fluxes. The fluxes are measured along with standard meteorological parameters (e.g. air temperature, humidity, precipitation) and these observations are made in order to estimate the impact of abiotic factors on peatland carbon balance. The preliminary results of the 10-years data set show a dependence between a net ecosystem CO₂ uptake and ambient temperature as well as the vegetation period beginning date.

One aim of the WETSCAPES project is to characterize macro- and microfossil remains in rewetted peat soils. Here, we present photographs of known and unknown remains found in macroscopic (magnification x 40) and microscopic (magnification x 400) analyses. We show how the combination of both methods helps to identify remains of different preservation stages and to describe them as retrievable morphotypes. Finally, we evaluate the indicator value of these morphotypes for the characterization of different peat layers including intermixed old and new material in rewetting contexts.

We present material from two percolation fen sites, one drained (Bad Sulze) and one rewetted (Tribsees). We recovered one peat monolith per site that was then frozen and subsequently cut into contiguous 0.5 cm slices of 6 x 12 cm. Subsampling of these slices allows macro- and microscopic analyses in close spatial linkage to additional microbiological, soil-chemical and physical analyses.

We show a variety of plant remains: radicel fragments, vascular tissue, epidermis cell clusters, infills of cells, and 'pustules' (cell fragment that form the basal part of root hairs). We can now identify some microscopic morphotypes at the level of the family or order (e.g. Poaceae, Cyperaceae or Poales) or even (although rarely) at the species level (pustules characteristic for Carex limosa).

Furthermore, we show a selection of non-pollen palynomorphs (NPP) covering diverse kinds of tissue, cell clusters and even single cells, as well as micro algal remains, fungal tissue and spores. This poster is an illustration to the oral presentation Mrotzek et al.: ‘Roots, tissues, cells and fragments – how to characterize peat from drained and rewetted fens’.

Roots, tissues, cells and fragments – what do we find in peat from drained and rewetted fens

Poster no.
T3-06

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WETSCAPES

Ecosystem production and its environmental controls in Rzecin peatland, Poland

Poster no.
T3-07

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Rising greenhouse gas emissions and climate change are putting peatlands in the focus as natural carbon sinks. In Germany, peatlands were drained for centuries, especially for agricultural and forestry use, with a strong intensification in the second half of the 20th century. Additionally, peat is used as substrate for horticulture. In total, 95 % of German peatlands are still drained and are now responsible for emissions of greenhouse gases such as carbon dioxide, nitrous oxide, and methane, as well as water polluting nutrients. In the context of a master thesis, we examined the actual state of three percolation fens in North-Eastern Germany. Two of these have been rewetted after decades of drainage, the other one was never deeply drained. Soil samples were extracted in depths between 10 cm and 250 cm on two to three different locations at the study sites. Different peat layers, types of peat material and decomposition degrees have been examined. Afterwards, the samples were analysed for several parameters like DOC, Fe, P, Ca²⁺, Al and Mn. Our work focussed on constituting the current state of the peatlands regarding carbon, nutrients, and decomposition. We assessed also Fe, because increased Fe levels could cause irreparable damage after rewetting, since Fe oxidizes in the topsoil. Moreover, most of the wetland plants can only tolerate low Fe concentrations. We hypothesised, that intensive drainage caused severe soil degradation. The degradation might possibly extend through all depths, so that the corresponding profiles might no longer be recognizable. We assume increased concentrations of DOC and P in the topsoil, indicating degradation as a result of drainage. Furthermore, we expect to find significant interdependencies between P, Al, DOC, and Fe.

Does peatland drainage initiate increased decomposition in deep peat layers?

Felix Besand
Anke Günther
University of Rostock

The cultivation of rewetted peatland areas with well-adapted marsh plants (paludiculture) is a new strategy that can be used to remove surplus nutrients from the soil and prevent their discharge into flowing waters. Since uptake patterns for most nutrient elements are not known for potential paludiculture species, seven species (Phragmites australis, Phalaris arundinacea, Typha latifolia, Carex acuta, Carex acutiformis, Glyceria maxima and Mentha aquatica) were studied for their uptake potential of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), iron (Fe), manganese (Mn), magnesium (Mg) and zinc (Zn). The aim of the work was to quantify nutrient uptake and to identify any differences among species. Plants were cultivated either in a specialised hydroponic nutrient solution (adapted Hoagland solution) or in a nutrient solution with a higher-dosed compound fertilizer. In order to determine the withdrawals, the solution was sampled at regular intervals and analysed for concentrations of the above-mentioned nutrient elements. Results indicated that species differed significantly in their uptake of the elements, their change in water parameters (pH, conductivity, oxygen content and evapotranspiration) and their increase in biomass. After three weeks, only very low nitrate-N concentrations (< 5 mg l⁻¹) were detectable in the containers of T. latifolia, C. acuta and C. acutiformis, which were therefore N-limited from this point on in both experiments. G. maxima, on the other hand, showed significantly lower weekly uptake rates than the other species. Nutrient uptake rates of the investigated potential paludiculture species suggest significantly different nutrient optima. The data collected here can be seen as a first orientation regarding the application of these species in paludiculture and their suitability for different site conditions.

Nutrient-uptake of potential paludiculture plants in standardized nutrient solution

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Recent investigations at Moor House (MH), UK, indicated a transition from plant material to superficial and deeper peat that became thermodynamically with a continuous increase in the degree of unsaturation of the organic matter. However, it is not clear whether these processes are universal or site-specific. Therefore, to test hypotheses developed at MH, peat formation and organic matter transitions were examined at a continental raised bog (Pürgschachen Moor, PM), Austria.

We sampled vegetation, dissolved organic carbon (DOC), and peat samples, dried, ground, and analysed them by elemental analysis (for CHN and O), bomb calorimetry, and thermogravimetry.

Thermodynamic limitation at the raised bog occurred in the top of the peat profile. However, DOC at both sites shows signs of chemical alteration compared to peat samples. As DOC export is an important pathway at MH, we deduce that DOC and the lack of pore water movement lead to a closed system and a rapid preservation of the peat in the raised bog. In contrast, mobile DOC and fluvial export promotes an open pore water system that drives further chemical reaction in the organic matter.

Our research indicates that, depending on relief and rainfall, there are distinctly different pathways of peat formation in blanket bogs compared to raised bogs. Furthermore, this provides chemical evidence of why high and static water tables preserve organic matter in raised bogs leading to higher carbon sequestration rates.

Contrasting mechanisms of peat formation between blanket and raised bogs

Poster no. T4-04

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Hydrobiogeochemical processes at the land-Baltic Sea interface using stable isotopes

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Land-sea interfaces are regions where physical and biogeochemical processes are important in modifying the continental fluxes of elements, nutrients and their isotopes to the oceans. Here, we report results from a study on isotope-hydrobiogeochemical investigations at the land-sea boundary at the southern Baltic Sea. The focus is on data of multiple isotopes (δ34S-SO4, δ18O-SO4, δ13C-DIC, δ18O and δ2H of H2O), nutrients, major and trace elements and physical parameters along the estuary of the Warnow River during 2017–2019 as well as the composition of the surface water of the Hütelmoor peatland during different seasons.

The results show that the Warnow estuary undergoes a temporal dynamic related with the discharge from the watershed and modified by Baltic Sea intrusion in the lower part of the river. Sulfur, oxygen and carbon isotopes of SO4 and DIC, respectively, pointed out different sources with an important Baltic Sea influence, mainly during inflow events. The Hütelmoor is a re-wetted peatland and the proximity to the Baltic Sea leads to event-type flooding by the brackish seawaters. This leads to spatially and temporally heterogeneous supply of dissolved salts with direct consequences for the biogeochemical processes in the carbon-sulfur cycles. The isotope measurements indicate the impact of anoxic soil solutions and an intense cycling of the sulfate that originates from the Baltic Sea. The mineralization of organic matter leads to an enrichment of the surface waters in isotopically light dissolved inorganic carbon.

Therefore, both systems presented a spatial and temporal dynamic partly affected by the water coming from the Baltic Sea. Furthermore, both coastal environments act as temporal storage reservoirs for precipitation, soil solution, (re)cycled sea and groundwater, influencing the biogeochemical processes before reaching coastal waters.
Denmark is a low-lying Nordic country, where many of the organic-rich lowland areas have been drained for agricultural use. In their undrained state, the lowland areas act as natural filters between upland agricultural areas and lowland aquatic ecosystems. Once they are drained, less water and nutrients are retained by the peatlands and instead drain to groundwater or as runoff. In addition, higher rates of carbon (C) and nitrogen (N) mineralization occur, and thereby higher concentrations of organic and inorganic N exist in the water draining from the peat.

It is therefore of interest to document how C and N species interact and how seasonal nutrient fluxes can be quantified in a cultivated Danish lowland.

An 8-hectare ditch-drained, cultivated lowland in the Nørreå stream valley in Jutland is being investigated for quantitative seasonal flow and dynamics of C and N. Water samples have been collected every 3–4 weeks since November 2018 from surface ditches and up to 206 piezometers with screens at various depths. Based on the analyses of these water samples and the monitoring of water flow in and out of the lowland, solute balances depicting the input and output of total organic carbon (TOC), dissolved organic carbon (DOC), total nitrogen (TN), nitrate (NO$_3^-$-N), ammonium (NH$_4^+$-N), and organic nitrogen (N$_{org}$) are constructed. Preliminary data indicate that the majority of N entering the lowland site originates from the upland groundwater aquifer in the form of NO$_3^-$-N, while N moving within the lowland soils is mainly present in the forms of NH$_4^+$-N and N$_{org}$. The majority of N movement through the lowland is via the ditches, and the forms of N seen in the ditches represent a mix of N-forms contributed directly from the groundwater aquifer (NO$_3^-$-N) and from water that had been in contact with organic lowland sediments (NH$_4^+$-N and N$_{org}$). The indicated flow paths allow the determination of the major N transformation processes taking place depending on C species amounts.
Effects of land management practices on phosphorus pools in a restored wet grassland on fen peat

In restoration projects, soil phosphorus (P) dynamics play a crucial role, since the bioavailability of P may affect the competitive dynamics as well as species composition in natural ecosystems. Particularly in the light of fen restoration, the remobilisation of redox-sensitive phosphorus has to be considered due to potential adverse effects on water quality in adjacent water systems.

Thus, we investigated the effects of rewetting duration and type of extensive wet grassland use on P fractions in a minerotrophic fen. We described P dynamics over a time scale of 17 years after the implementation of restoration measures (sampling 0, 3, 5 and 17 years after the start of restoration). The restoration measures included extensive grassland use (mowing, grazing and a combination) and a controlled water management. During the winter months the drainage ditches were blocked, which facilitates increased water levels and temporary inundation events. During summer, the grassland practices require low water levels to ensure trafficability. The topsoil samples were analysed for their total P (P\text{t}), plant available P (PDL), organic P (P\text{org}) and additionally for iron (\text{Fe}). We analysed the influence of rewetting duration and kind of grassland use on P fractions by ANOVA (mixed model) and in the case of significant effects, we compared the mean values using Tukey’s HSD. The effects of iron and waterlogging on the PDL content were investigated by regression analysis.

We found significant effects of both kind of extensive grassland use and rewetting duration on PDL contents. No interactions between type of use and rewetting duration were detected. P\text{t}, however, showed no dependence on restoration duration and management. Long-term extensive grassland use has the potential to reduce PDL. Fe was positively correlated with P\text{t}, but negatively with PDL in case of mown plots with considerable P export rates. These results are of relevance for further restoration efforts on organic soils.

Spatial variability of soil properties in relation to topography in a rewetted coastal fen

Fen peatlands over the past century have faced wide range degradation through drainage for agricultural intensification, making them one of the most threatened ecosystems in Europe. However, over the last three decades, restoration of degraded peatlands has gained importance. Although, there has been an increased research interest on mires and peatlands, spatial research on hydrophysical soil properties following rewetting in coastal fens is lacking. Therefore, to understand the effect of rewetting on peat accumulation and its hydrophysical properties in relation to space and topography, soil organic matter content (SOM) and hydraulic conductivity (Ks) of top soils (10–15 cm) were investigated in a rewetted coastal fen. Both SOM and Ks were spatially auto-correlated within 95 meters and 77 meters, respectively. A map of SOM was generated using simple kriging, which predicts higher organic matter content in the centre of the ecosystem at lower elevation where water levels are higher. At the edges of the study area, at higher elevation, SOM decreases. Lower elevations in the centre of the ecosystem provide a wetter and therefore more anaerobic environment, enabling peat growth. Although SOM is known to be a good indicator of Ks, our results yielded only a moderate correlation. We conclude that soil surface elevation even at small scales is an important aspect to consider for peat accumulation and therefore for the restoration of coastal fen peat, especially at the Baltic Sea coast, where soils are not subjected to significant tidal flooding.
Water flow in a rewetted coastal peatland and across the coastline

Coastal peatlands are a common feature of the southern Baltic Sea coast. They are characterized by intense interactions between the land and the sea, affecting the biogeochemical processes in both ecosystems. Fresh water and nutrients are delivered from the peatland to the sea by submarine groundwater discharge (SGD) and/or drainage ditches, while flooding during storm surges brings saltwater into the peatland. Human interventions have dramatically changed the hydrology of most peatlands by intensive drainage, the construction of flood protection structures and recent rewetting measures. The objective of this study was to reveal the flow pathways in a recently rewetted coastal peatland and the exchange processes with the Baltic Sea. The study site is located in northeastern Germany and is composed of 1–3 m peat overlying 3–10 m fine sands. Seventeen groundwater and ditch observation wells are equipped with CTD loggers.

Under current conditions, the water level in the peatland is largely aboveground. Although the outlet of the peatland is blocked, the ditches play an important role in equilibrating the water level and transporting solutes. Infiltration into the strongly decomposed peat is low. Groundwater flow in the sand aquifer is directed towards the sea, but very slow. Therefore, fresh SGD is small and consists to a large part of groundwater recharged in the dune dike. No saltwater wedge is present under the peatland. However, a legacy effect of past inundations with seawater is observed: The salinity in the peatland ranges from 3–5 both in the peat and the sand aquifer with only small temporal variability. Dating of the groundwater in the sand aquifer using the \(^{3}H/^{3}He\) method showed that most of the water infiltrated before 1950, only on the edge of the peatland it originated from the year of rewetting. A 3D numerical groundwater flow model is currently used to simulate water flow and salinity distribution under different stages of drainage and rewetting.

Effect of anisotropy on solute transport and phosphate release in peatlands

Peat soils are heterogeneous, anisotropic porous media. To date, there is still limited understanding of contaminant transport in anisotropic and heterogeneous peat soils. In this study, we aimed to explore the effect of anisotropy on solute transport and phosphate release from peat soils. Undisturbed soil cores (vertical and horizontal directions) were collected from one drained and one restored peatland both in a comparable state of degradation. Saturated hydraulic conductivity (K\(_s\)) and chemical peat properties were determined for all soil cores. Miscible displacement experiments were conducted on soil cores under saturated steady state conditions using KBr as a conservative tracer. The results showed that (1) the K\(_s\) in vertical direction was significantly higher than that in horizontal direction (K\(_{sv}\)), indicating that K\(_s\) behaves anisotropic; (2) solute transport parameters (D and \(\beta\)) as derived from model optimization employing the mobile and immobile model exhibited likewise anisotropic behavior; (3) stronger preferential flow with a shorter relative 5% arrival time occurred in vertical direction, where higher K\(_s\) values were observed; (4) phosphate release was observed from drained peat only. Both anisotropy and soil heterogeneity influenced phosphate leaching. The soil core with the strongest preferential flow released the largest amount of phosphate. We conclude that the anisotropic properties of peat soils should be considered in peatland hydrology and biogeochemical models as well as in peatland restoration projects.
Influence of microsite conditions on *Alnus glutinosa* growth in a rewetted peatland

Alder swamps are often highly degraded due to drainage for intensive forestry. Studies have shown that, if properly done, the rewetting of formerly drained alder swamps combines benefits for forestry, climate change mitigation and waterbody protection. Although some studies have shown that rewetting alder swamps can largely affect the tree-vitality when the area is flooded, other experiments have revealed the possibility of preventing tree die-offs by a managed, stepwise rewetting.

The aim of this study is to explore the influence of microsite conditions, tree demography and tree metrics on the reaction of an alder stand to a rewetting to provide guidance for forest rewetting management. Sampling took place in an alder swamp in NE-Germany that was rewetted in 2005. For each tree on the site (~280 individuals), we measured tree height, stem diameter, social status and vitality. Two increment cores were taken per tree for measuring tree ring widths (TRW) and wood density variations. In addition, the distance to the swamp centre, the surrounding vegetation and the relative terrain altitude were recorded for all trees. Preliminary results of TRW analysis indicate that the rewetting had a significant impact on tree growth. Microsite conditions, especially relative terrain altitude, and tree-height seem to have a substantial influence on trees’ reaction to the rewetting. Annual density variations seem to be more correlated to microsite conditions than TRW. Our study shows that microsite conditions, tree metrics and demography have an important influence on alder trees’ reaction to rewetting. They should therefore be considered in future rewetting management planning for preventing alder die-off.

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Tory Hill SAC protected fen habitat

Tory Hill SAC is a protected fen habitat. An Office of Public Works (OPW) statutory maintained channel drains the fen. The OPW in cooperation with National Parks and Wildlife Service (NPWS) have undertaken to restore this fen to a favourable conservation status. Several studies have been completed on the hydrological regime of the fen with supporting ecological surveys. Works are ongoing with plans to install boreholes, to ascertain the groundwater catchment to the fen and the adjacent lake and OPW drain.

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Reversing the San Joaquin-Sacramento River delta’s decline through paludiculture

The Sacramento-San Joaquin Delta peatlands are an important example of soil oxidation and subsidence. About 5 billion cubic meters of peat accumulated during the last 7,000 years of wetland development. Drainage of the peatlands, which began in the 19th century, has resulted in the loss of about one-half of this volume to date and is on-going. Soil loss has resulted in land surface elevations as low as 9 m below sea level. Subsidence, which threatens levee stability, continues at rates ranging from about 0.5 cm to over 2 cm per year on about 80K ha in the western and central Delta and generates approximately 35 mt ha⁻¹ of CO₂eq emissions per year. Agriculture is the pre-dominant land use and crops such as maize, alfalfa and wheat dominate on peat soils. A paludiculture project will begin in October 2019 with re-flooding for the production of *Typha* spp., and *Scirpus acutus* for biomass. Biomass will be converted to biomethane and used for transportation fuels. California’s aggressive climate policies should support paludiculture as an economic alternative to drained agriculture.
Disproportionally high CO₂ emissions and losses of characteristic biodiversity are caused by drainage-based utilisation of fen soils for agriculture and forestry. Rewetting followed by site-adapted land use (paludiculture) can effectively lower emissions and may restore habitats for characteristic fen species. However, the spatial potential of such sustainable land use options and their impacts on greenhouse gas (GHG) emissions and biodiversity have not yet been evaluated in detail in key peatland-rich federal states of Germany. Within the project KLBB – Climate-friendly and biodiversity-promoting use of fen soils (2018 – 2019), we develop guidelines for peat-preserving utilisation of temperate fen soils motivated by climate protection and biodiversity enhancement. First, we define criteria for an evaluation of the suitability of the area for peat-preserving land use options. According to these criteria, suitability maps for three peatland-rich German federal states are prepared. Promising land use options for wet fen soils (ranging from traditional approaches such as pastures and reed cutting for thatch to innovative options like energy generation from fen biomass) are described regarding implementation and economics. The potential reduction of GHG emissions is assessed both for the land use options and for the studied federal states according to the suitability maps. The effects of rewetting and various land use options on biodiversity, potential benefits, losses and trade-offs for biodiversity are identified on a literature-based review. Possibilities to increase benefits for fen-typical biodiversity are described and assessed with respect to costs. The project’s results can feed directly into national and regional policies via the Federal Agency for Nature Conservation and a working group of all German peatland-rich federal states. Alongside, improving regulatory conditions and financial incentives is important for paving the way for future independent implementation by farmers.
Cultivated organic soils (7–8% of Norway’s agricultural land area) are economically important sources for forage production in some regions in Norway, but they are also ‘hot spots’ for greenhouse gas (GHG) emissions. The project ‘Climate smart management practices on Norwegian organic soils’ (MYR; funded by the Research Council of Norway, decision no. 281109) will evaluate how water table management and the intensity of other management practices (i.e., tillage and fertilization intensity) affects both GHG emissions and forage’s quality and production. The overall aim of MYR is to generate useful information for recommendations on climate-friendly management of Norwegian peatlands for both policy makers and farmers. For this project, we established two experimental sites on Norwegian peatlands for grass cultivation, of which one in Northern (subarctic, continental weather) and another in Southern (temperate, coastal weather) Norway. Both sites have a water table level (WTL) gradient ranging from low to high. To explore the effects of management practices, controlled trials with different fertilization strategies and tillage intensity will be conducted at these sites with WTL gradients considered. Meanwhile, GHG emissions (including carbon dioxide, methane and nitrous oxide), crop-related observations (e.g., phenology, production), and hydrological conditions (e.g., soil moisture, WTL dynamics) will be monitored with high spatiotemporal resolution along the WTL gradients during 2019–2021. Besides, MYR aims at predicting potential GHG mitigation under different scenarios by using state-of-the-art modelling techniques. Four models (BASGRA, Coup, DNDC and ECOSSE), with strengths in predicting grass growth, hydrological processes, soil nitrification-denitrification and carbon decomposition, respectively, will be further developed according to the soil properties. The project „DESIRE“, supported by Interreg Baltic Sea Region Programme 2014–2020, started in January 2019. It comprises a mixed approach of drafting policy recommendations, generating new knowledge via modelling, and using pilot sites to demonstrate peatland rewetting and implementation of paludiculture. The project aims to increase the capacity of policy makers and other decision makers to adopt policies that incentivise peatland management for nutrient retention via enhanced institutionalized knowledge and competence and more efficient use of human and technical resources. DESIRE focuses on numerous disturbed peatlands in the Neman catchment and will exemplarily restore some of them to act as wetland buffer zones (WBZ). The ability of rewetted peatlands to catch nutrients will be enhanced with innovative land use practices, i.e., harvesting of nutrient-rich biomass from rewetted peatlands. Specific policy instruments like river basin management plans and agri-environmental schemes will be analysed and adapted or newly developed within the project to provide instruments and incentives for stakeholders. Economic evaluation of the pilot projects will showcase cost-effectiveness of the proposed ecosystem-based measures in comparison to other, more technical installations for nutrient filtering and retention. The project is led by Greifswald University supported by the Succow Foundation (Greifswald), cooperating with partners in Poland (Warsaw University of Life Sciences/SGGW, Polish Society for the Protection of Birds/OTOP, Bialystok Technical University), Lithuania (Vytautas Magnus University, Lithuanian Fund for Nature), and Russia/Kaliningrad oblast (Ministry for Natural Resources and Ecology of Kaliningrad Region, Natural Heritage NGO). Further institutions in Lithuania, Poland, Kaliningrad and Belarus will act as associated organisations.
Excursion Guide
The excursion locations in Mecklenburg-Western Pomerania from left to right:

**Excursion 2:**
Coastal mire (paludification peatland) and beach;

**Excursion 1:**
Alder carr;

**Excursion 3:**
River valley fens;

**Excursion 4:**
Coastal peatland and Greifswald Mire Centre.
Excursion 1

“Hike through an alder carr”

This half-day excursion brings us to the small village Wöpkendorf located between the two university cities Rostock and Greifswald. On our hike to the alder carr, we will pass an old Slavic settlement place with remnants of an early medieval Slavic fortress from the 9th century. A circular hillfort and moat bear witness of the Slavic settlement period in the region. Passing intensively drained and managed meadows, we enter the forest near an impressive field oak, witness of former forest pasture. We will circumnavigate the so-called Bauernmoor (farmers’ mire), a ~10 ha size groundwater fed mire, filling a small depression in the young morainic landscape. The history of the mire is well documented in maps since the end of the 17th century. Back then, it was used as a pasture and only sparsely forested, although most likely already (partially) drained. At the end of the 19th century, forest pasture land was abandoned and an alder-ash forest developed. Around 1900, the mire was effectively drained and managed as production forest. In the centre of the mire, an island-like mineral ridge is situated that was forested by pine and spruce. The wetter parts are dominated by alder (Alnus glutinosa L.) and ashes (Fraxinus excelsior L.). Poor maintenance of ditches led to an increasing occurrence of waterlogging since the 1990s. Finally, in 2003 an active rewetting of the depression was initiated with a maximum water level of 1.30 m above the surface. Due to this significant and sustained water level increase, most of the trees died, and only a few alders survived. To date, resprouting and rejuvenation of mostly alder on the dryer mounds (“Bulte”) initiates the next forest generation, which is expected to be better adapted to these wetter conditions. We will observe the vegetation change in the peatland and come across old beeches and oaks growing adjacent to the mire that have preserved a memory of past water table fluctuations in their annual increments (tree rings). Finally, we will visit the WETSCAPES monitoring plot, with detailed instrumentation of above- and belowground growth and peat formation/decomposition processes, which was installed in 2017 at the peatland margin. Here at the peatland margin, a more moderate water level increase allowed for adaptation and survival of established alder trees. Typical for alder carrs, strong intra-annual water level fluctuations with water tables about 40 cm aboveground in winter/spring and several decimetres belowground in summer/autumn lead to interesting dynamics in biomass accumulation and decomposition. At the monitoring plot, we will explain the installed instrumentation including minirhizotrons, point-dendrometers, sap-flux sensors and gas-flux measurements. We expect to be back in Rostock at about 1 p.m.

Table of Contents
Excursion 2
“Trip to a coastal mire and Baltic Sea beach”

This excursion brings us to the nature reserve „Heiligensee & Hütelmoor“ a coastal peatland complex that is located within the city boundaries of Rostock as part of the „Rostocker Heide“ the municipal forest of Rostock and the largest continuous forest at the German coasts. The excursion starts and ends at the StrandResort Markgrafenheide. We will first follow a path on top of the dune dyke that is (still) protecting the reserve from flooding with Baltic Sea water to the northeast with beautiful views both of the sea and into the peatland. At the Rosenort („Ort“ is the local term for very gentle, almost unrecognizable capes) we will turn into the forest and head landwards to reach the main entry point of the reserve from the forest side where you will be introduced to this central research site of the DFG research training group Baltic TRANSCOAST. Depending on water levels we can directly cross through the area or we proceed by surrounding the southern margin of the peatland where we have several opportunities to climb lookout towers for stunning views of the relatively large peatland area.

THE NATURE RESERVE „HEILIGENSEE AND HÜTELMOOR“ (ADAPTED FROM JURASINSKI ET AL. 2018)
The nature reserve „Heiligensee und Hütelmoor“ (in brief and in the following „Hütelmoor“) is located on the southern Baltic Sea coast in north-eastern Germany, near the city of Rostock and the estuary of the river Warnow. The reserve stretches over an area of 540 ha with 315 ha covered by peatland. A local depression shaped by a former glacial stream (Kolp, 1957) served as basis for the development of a fen peatland that formed when the rising sea level of the Baltic Sea (driven by isostatic movements of the earths crust after the melting of the ice at the end of the last glacial) caused rising groundwater levels on the land side. The climate is temperate in the transition zone between maritime and continental with an average annual temperature of 9.1°C and an average annual precipitation of 645 mm (data derived from grid product of the German Weather Service, reference climate period: 1981–2010). The evapotranspiration amounts to 620 mm a⁻¹ in open water and 581 mm a⁻¹ in reed areas (Miegel et al., 2016).

The main parts of the area represent coastal paludification fens, and the largest portion of the peatland is covered by 1 to 3 m thick layers of sedge and reed peat. Due to its low elevation (<0.2 to +0.7 m NN), the site was influenced by intermittent flooding events, resulting in the formation of thin sand layers within the peat in some areas. In the surroundings of the Heiligensee („Saints’ Lake“ in English), organic or mineral lake sediments are found at the basis of the peat. Underneath the peat, 3
Maps of the peatland area in the nature reserve „Heiligensee & Hütelmoor” over time. Left: Already in the map of Wiebeking in 1786 the main ditch system is visible. At this time the map also shows an outlet from the area directly into the sea. Center: 100 years later, in the Preussisches Urmesstischblatt (1888) the ditch system and the open areas have not changed much. Right: Same holds for the situation another 130 years later (contemporary topographic map).

In the 1990s, the study site was moderately rewetted and grasses were cut once a year to keep the vegetation open. Extensive mowing supported the aims of nature conservation to preserve a resting site for migratory birds while allowing the restoration of the typical fen vegetation. The mean growing season water level during that time was close to the surface (Koebusch et al., 2013). However, water levels dropped to 70 cm below the surface during summers, which raised concerns about ongoing aerobic peat decomposition (today we have indications that this was not the case). Therefore, a ground sill was installed in the outflow of the catchment in winter 2009/2010 which initiated a year-round shallow flooding for most areas of the study site (mean growing season water level 37 cm, values indicate flooding). The discharge from the peatland averages 44 L s⁻¹, but stops during summer months when the water level drops below the ground sill (Miegel et al., 2018). Rewetting projects are common for much of the Baltic Sea coast where nature conservation has been given priority. Until 2018, the vegetation was dominated by emergent macrophytes such as Common Reed (Phragmites australis (Cav. Trin.). Especially in the second part of the vegetation period submerged aquatic species like Soft Hornwort (Ceratophyllum submersum L.) dominated the relatively abundant areas of open shallow water. The typical brackish water emergent macrophyte Sea Clubrush (Bolboschoenus maritimus L.) was almost completely displaced, whereas another brackish water species, the Softstem Bulrush (Schoenoplectus tabernaemontani (C.C.Gmel.)) Palla, was able to increase its cover considerably over the last decade (Koch et al., 2017). Dryer areas at the boundaries to the forest are mainly colonised by the Lesser Pond Sedge (Carex acutiformis Ehrh.) and the Common Rush (Juncus effusus L.). Due to a very dry year 2018 the water levels dropped below ground surface in almost all parts of the reserve leading to a massive colonization with Marsh fleawort (Tephrosia palustris (L.) Pourr.) and other species (see talk by Koebusch et al. during the conference). Drainage and agricultural use led to aeration and mineralization of the peat resulting in a highly degraded top horizon. The soil type was identified as sapric histosol before rewetting. The remaining peat body is moderately to strongly decomposed with substantial heterogeneity of physical and chemical properties. Rewetting measures and permanently high water levels (above peat surface) have led to the sealing of the soil surface because of sedimentation of fine particles. The former soil surface now resembles a lake bottom surface, with the possible formation of a gytja (a characteristic layer composed of either organic or mineral material that can be typically found beneath fen peats, and which is considered as the initiation stage of fen peat formation). The ongoing sealing process at the soil surface limits the vertical infiltration, thus, possibly changing the hydraulic functioning of the entire wetland.

A dune dyke was installed at the coastline of the fen in 1903 for coastal protection of the nearby seaside resort Markgrafenheide and was reinforced in 1963 (Miegel et al., 2016). Already before 1903 there was a natural sand dune providing a barrier between the Baltic Sea and the Hütelmoor. Due to the artificial dune dyke the peatland has been almost completely cut off from the Baltic Sea. The last intrusion before a new breach in January 2019 (see end of paragraph) happened during a storm night in November 1995 (Bohne and Bohne, 2008). Afterwards, the dune dyke was rebuilt and strengthened. It is, however, not maintained anymore since the year 2000. It has been anticipated that the natural impact of the sea including episodic flooding will re-establish and, thus, result in repeated input of brackish waters (on decadal time scales) with possible consequences for hydro-physical and biogeochemical processes. A storm flood event in January 2017, which washed away considerable parts of the dune dyke at places where it was more than 20 meters
wide, failed to flood the study site. In January 2019, however, two storm floods within a week were able to breach the dune dyke and caused a major inflow event. We are now in the process of investigating the consequences of this major inflow on the biogeochemistry of the peatland and on the vegetation development.

THE MARINE SIDE: SHALLOW COAST OF THE BALTIC SEA

A mosaic pattern of eroding cliffs and sand deposition areas are dominant along the western part of the Baltic Sea coast in northeastern Germany. Due to coastal erosion and isostatic sea level rise the coastline has shifted landwards at the study site exposing former land-based geological strata to the sea. The peat that once developed on land now extends to the sea, forming a unique habitat for micro- and macro-phytobenthos. Most of the coastal area between 0 and 10 m depth is covered by coarse-grained sediments with gravel and cobbles dominating at some sites. In the northern area of the study site, gravel and coarse sands are abundant on the sea bottom surface whereas in the south, fine and medium sands dominate (for details and a map, see Kreuzburg et al., 2018). This is typical for sea floor near the coast because coastal waves and prevailing south-westerly winds generate longshore currents, displacing the small particles and transporting them along the coast and towards greater depths. A few tens of meters away from the shoreline an underwater longshore bar has developed. This seems to be typical for the southern German Baltic coastline where no fine-grained sediments can be found (Tauber, 2012). Roughly 10 km west from the study area, the Warnow estuary enters the Baltic Sea. The Warnow river basin is approximately 3,000 km² in size with elevation differences of less than 100 m as is typical for lowland catchments mainly used for agriculture (Bahnwart et al., 1998, Deutsch et al., 2006). The river mouth is located 15 km landwards where a weir prevents seawater to travel further upstream. A gauging station is located at the weir and discharge is continuously recorded. The mean outflow rate is 16.5 m³ s⁻¹ with a mean nitrate concentration of 1.78 mg N L⁻¹ (or 127 µmol L⁻¹, lung.mv-regierung.de). A small surface plume extends a few kilometers west – and northwards along the estuary while the salinity increases to the typical brackish values of 10–15 PSU. During the passage, inorganic nutrients are entirely consumed or mixed so that only recalcitrant substances like dissolved organic material of the plume are able to reach the study site off the Hütelmoor. Jurasinski et al. (2018) provide a comprehensive overview of recent research results from the area.

REFERENCES

Hydrologie und Wasserbewirtschaftung 60:242–258
Excursion Guide

Excursion 3

“Historic and recent land use of river valley fens”

LANDSCAPE
Percolation mires are one of the most common peatland types in north-eastern Germany. They formed after the last glacial period (~10,000 years BP) in meltwater channels left by the retreating ice. Rising sea water levels during the Littorina transgression (~7,000 BP) flooded the valleys and caused the formation of deep peat bodies of mainly reed and sedge origin on top of organic silt layers. Percolation mires are characterized by a constant stream of ground water, moving more or less horizontally through the peat body towards an open water body (Succow & Joosten 2001). The former percolation mires in the two river valleys of the Recknitz (old slavic: “little river”, Kühnel 1881) and Trebel belong to the largest connected fen complexes in northeastern Germany, together covering ~13,000 ha (Ratzke 2000). Today, they still contain up to ~8 m deep peat. Although they never merge, the stream courses of the two rivers at one point almost meet before flowing into opposite directions. Usually up to 3 km wide, the peatlands of two river valleys here reach a combined extent of ~5 km (Figure 1). Ground water moving horizontally through this large peatland complex caused low nutrient levels in the peat on the water divide in the middle of the peatland. ~2000 years ago, this initiated the formation of ombrotrophic peat, which over time covered ~400 ha and reached a thickness of >1 m.

GENERAL LAND USE
The name of the bog between the rivers Trebel and Recknitz (“Grenztalmoor”) relates to the fact that for centuries the official border between Mecklenburg and Pomerania was located directly on the peatland. Early Swedish maps (“Schwedische Matrikelkarte”, 1697) indicate “Forest and Pasture” utilization of the region surrounding the “Grenztalmoor”. Until then, the bog complex had not yet been significantly drained (Gremer & Michaelis 2003). The 18th century saw the construction of two large channels through the bog as transport pathways for peat dedicated for the salt works in the town Bad Sülze (see box). Since the “big peatland fire” (“Großer Moorbrand”) in the 1950s, the former open areas in the bog were colonized mainly by pine trees and birches. In 1971, the bog complex “Grenztalmoor” was declared nature reserve in order to protect and regenerate endangered flora and fauna typical for bogs.
DEEP DRAINAGE DURING THE 20TH CENTURY

Percolation mires were especially suited for intensive agricultural use, since they were easy to drain and initially very fertile (Succow & Joosten 2001). Accordingly, after being mainly moderately drained and used as a pasture in summer, complex hydrological reconstructions were started in the Recknitz and Trebel valley to intensify cultivation of the fen areas in the 1960s. The works included e.g. channeling of the river beds, deepening and re-organization of the ditch system and construction of a pumping station. Finally, the existing fen areas were deeply ploughed, sown, and fertilized for use as intensive grasslands. After a few years of high agricultural production the former percolation mires quickly degraded and yields decreased. As a result of the widespread and deep drainage, percolation peatlands in Mecklenburg-Western Pomerania subsided by > 1 m within few decades (Succow & Joosten 2001, p. 431).

REWETTING IN THE TREBEL VALLEY

The early 1990s were characterized by a short period of abandonment in the Trebel valley following German reunification. Later, the area was rewetted together with over 3000 ha of peatlands along the river valley in a program that was financed by EU-LIFE. As part of the program, a hydrological protection zone was established surrounding the former bog complex by deconstruction of pumping stations and blocking of drainage ditches in summer 1997 (Bönsel & Runze 2005). Since these measures were not sufficient to raise the water table to a satisfactory level, a second phase of the program followed in 2001 (Bönsel & Runze 2005). Since then, water levels have stabilized around ground surface. As a result of the higher water levels, forest cover has strongly decreased in the nature reserve (Koska 2007).

SALT PRODUCTION IN BAD SÜLZE

In the town Bad Sülze, salt had been produced from a local salt spring since at least 1243 (Mecklenburgisches Urkundenbuch, Landeshauptarchiv Schwerin). After being run mostly by individuals earlier, the salt works were centralized and modernized in 1744. Large graduation towers were constructed to concentrate the brine by natural evaporation before heating. In order to heat the salt pans, peat was extracted from the nearby peatlands as fuel from 1553 (Succow & Joosten 2001, p. 405). For this purpose, deep channels were dug through the peatland to ship peat from the extraction site to the salt works. The biggest of these channels was called the "Prahmkanal", after the type of small boat that was used for transportation ("Prahm"). Since the 19th century, prices for cooking salt decreased due to the growing trade by railway. The salt works in Bad Sülze were unable to compete with these low prices and had to close in 1907.

FURTHER READING


LINKS

WETSCAPES project: https://www.wetscapes.uni-rostock.de/en/
Salt Museum in Bad Sülze (German): https://www.salzmuseum-badsuelze.de/
Excursion 4
“Coastal flood mire and research at the Greifswald Mire Centre”

COASTAL FLOOD MIRES AND SALT MARSHES.

In coastal flood mires, peat accumulation raises the surface above sea level, which results in an effective coastal protection that stabilises the coastline in spite of climate induced sea level rise. Besides this practical value, coastal flood mires are also a haven for large numbers of migrant bird species. The total area of coastal flood mires in Mecklenburg-Western Pomerania has declined dramatically over the years. From about 21,000 ha in the early 20th century, only 3,000 ha have survived until today. Already several hundred years ago, dikes were built to cut off the mires from flooding. The mires were drained and used as grasslands and arable fields. Years of drainage resulted in oxidation of the peat layers and subsequent lowering of the surface. After the economic turnover of the early 1990s, these lands were abandoned. In the absence of grazing cattle, the typical salt marsh vegetation could not reestablish and a succession to brackish reeds started.

KARRENDORF MEADOWS AND KOOS ISLAND

The lagoon shore (Boddenküste) of Western Pomerania is known as ‘a coast with two coastlines’. The Bodden, shallow water bodies originating from the Holocene transgression of the Baltic Sea, line up in the interior of the outer coast and form a second coastline. The shore of the Bodden provides a unique, tideless habitat with low salinity. Whereas the outer coast is dominated by cliffs, dunes and sandy beaches, the inner Bodden shoreline is characterised by salt meadows and reed beds. Conditions for plant and animal life in the salt marches include ever-changing salinity due to irregular floods. We find a number of well-adapted and rare species here. Moreover, salt meadows once functioned as semi-natural coastal protection. In the 1960s, however, dikes were built and subsequent drainage destroyed most salt meadows in our region. The Karrendorfer Wiesen (Wiesen= meadows), 10 km north of Greifswald, are part of the morainic plain of Western Pomerania.

Registration, boarding

08:15 – 08:30

• Registration, boarding

08:30 – 09:15

• Bus transfer to A20 exit Tribsees // Explanation of the programme, description of the landscape

09:15 – 09:45

• Short stop A20 building site near Tribsees // Collapsing highway bridge into a fen, causes, public perception

09:45 – 10:30

• Bus transfer to Karrendorf village

10:30 – 12:30

• Visit to restoration site and WETSCAPES research plots, walk to Koos Island

12:30 – 13:30

• Lunch

13:30 – 14:30

• Walk from Koos Island back to Karrendorf

14:30 – 14:45

• Bus transfer to Greifswald, Soldmannstr. 15

14:45 – 15:45

• Group 1: Visit to mesocosm facility

• Group 2: Visit to PeNCIL + peatmoss nursery

15:45 – 16:45

• Group 1: Visit to PeNCIL + peatmoss nursery

• Group 2: Visit to mesocosm facility

16:45 – 17:00

• Bus transfer to Arboretum

17:00 – 17:30

• Visit to PRIMA mesocosm experiment

17:30 – 18:45

• Bus transfer to Rostock

19:00 – 20:00

• Dinner

20:00

• Own leisure time

20:30

• Evening talk: “Coastal flood mires and research at the Greifswald Mire Centre”

Lead:

Dr. Franziska Tanneberger

University of Greifswald & Greifswald Mire Centre
Paludiculture is a peat-conserving sustainable form of productive land use on peatland, which avoids the GHG emissions and other forms of pollution resulting from drainage-based land use. The objective of paludiculture is to maintain and restore the multiple services provided by wetland ecosystems, while at the same time allowing biomass harvest. Paludiculture is thus an agri- (or silvi-) cultural production system: it targets the production of plant- or animal-based commodities. Paludiculture is the use of peatlands under wet site conditions and implies an agricultural paradigm shift. Instead of draining mires for producing biomass and increasing load-bearing capacity, peatlands are used under peat-conserving hydrological conditions. Deeply drained and highly degraded peatlands have, from an environmental point of view, the greatest need for action, and provide the largest land potential for paludiculture.

**RESEARCH PLOTS OF THE WETSCAPES PROJECT**

Since 2017, the WETSCAPES project brings together researchers from Rostock and Greifswald universities for intensive integrated basic landscape-ecological research at high spatial and temporal resolution in both a drained and a rewetted part of Karrendorfer Wiesen. A multitude of techniques is used to study primary production, metabolic processes, matter transport, gas exchange and peat formation. The EU BiodivERsA project REPEAT links the site to a network of some 100 sites across Europe where peat formation is assessed in 2017–2020.

**GREIFSWALD MIRE CENTRE**

The mesocosm unit at Greifswald University combines below-ground research in typical fen mire plant communities with automatic above-ground measurements and (in future) greenhouse gas flux measurements. With field scales and the PlantEye multispectral 3D scanner, site condition maintenance and above-ground measurements are run largely automatically. Results of pilot studies as well as of first-hand experience will be presented.

The Greifswald Mire Centre hosts five main sources of information concerning peatlands:

- the Database of Potential Paludiculture Plants (DPPP)
- the Global Peatland Database (GPD)
- the Peatland and Nature Conservation International Library (PeNCIL)
- the knowledge platform for the general public MoorWissen (German only)
- a peatland greenhouse gas emission database for temperate peatlands

The GPD is a project of the International Mire Conservation Group (IMCG) and is managed by the Greifswald Mire Centre. It provides an overview of the extent and degradation status of peatlands/organic soils in 268 countries and regions of the world. It mainly contains digital data, but also information from printed sources of the Peatland and Nature Conservation International Library (PeNCIL). A database of hundreds of digital photos of peatlands from all over the world is linked to the GPD. Since 2012, the information on peatlands/organic soils is transferred into a spatially explicit GIS-GPD. The GIS-GPD is continuously updated and improved and can be supplemented with additional information on peat thickness, carbon content, vegetation and mire type. In addition, GIS data sets from other mapping projects are evaluated and integrated. Global coverage by 2020 is being sought; a Global Peatland Map is in progress since 2019. Current projects on data collection and peatland mapping include Northeast and West Africa, Northeast China, Indonesia, Papua New Guinea, Iran and Cuba. The Peatland and Nature Conservation International Library (PeNCIL) is a globally unique collection of ca. 25,000 publications related to peatlands; the large peat moss collection for genetic research and to facilitate cultivation, the paludarium is a special section of the Botanical Garden dedicated to peatland plants etc.

If time allows, we will also visit GMC’s peatmoss nursery. Twelve peatmoss species are growing here. The project MOOSzucht intends to identify the species growing best under site conditions in (Northwest) Germany to reach high yields and produce large amounts of renewable biomass to substitute peat in horticulture. Nearly 500 samples of wild provenances across Europe – from Ireland to Estonia, from Sweden to Czech Republic and in Georgia – were collected within the MOOSzucht project as the basis for research.
The PRIMA project mesocosm experiment uses Typha angustifolia, Typha latifolia, and 5 clones of Phragmites australis to test the influence of nutrients and water level under controlled conditions. The aim of this experiment is to derive optimal management strategies (water level, nutrient availability) for growth and vitality of the tested species and varieties. The utilization parameters will be realized in field experiments and developed based on genetic characterization.

THE GREIFSWALD MIRE CENTRE
The Greifswald Mire Centre (GMC, www.greifswaldmoor.de) is a strategic cooperation between the University of Greifswald, the Michael Succow Foundation, and Düne e.V. The GMC strengthens and consolidates as an integrative umbrella brand all peatland-related activities in Greifswald and develops into a regionally and globally interconnected, influential interface, where basic and applied research is carried out, know-how is transferred, and inter- and transdisciplinary science-based policy and corporate advice is provided.

LINKS
WETSCAPES project: https://www.wetscapes.uni-rostock.de/en/
Michael Succow Foundation: http://www.succow-stiftung.de/home.html
Greifswald Mire Centre: https://greifswaldmoor.de/home.html
Databases of the Greifswald Mire Centre: https://greifswaldmoor.de/databases.html
PRIMA project: https://www.moorwissen.de/de/paludikultur/projekte/primaprojekte/index.php
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