




Active afforestation of drained peatlands is not a viable option under the EU Nature Restoration Law

Gerald Jurasinski , Alexandra Barthelmes, Kenneth A. Byrne, Bogdan H. Chojnicki, Jesper Riis Christiansen, Kris Decler, Christian Fritz, Anke Beate Günther, Vytas Huth, Hans Joosten, Radosław Juszcak, Sari Juutinen, Åsa Kasimir, Leif Klemedtsson, Franziska Koebisch, Wiktor Kotowski, Ain Kull, Mariusz Lamentowicz, Amelie Lindgren, Richard Lindsay, Rita Linkevičienė, Annalea Lohila, Ülo Mander, Michael Manton, Kari Minkkinen, Jan Peters, Florence Renou-Wilson, Jūratė Sendžikaitė, Rasa Šimanauskienė, Julius Taminskas, Franziska Tanneberger, Cosima Tegetmeyer, Rudy van Diggelen, Harri Vasander, David Wilson, Nerijus Zableckis, Dominik H. Zak, John Couwenberg

Received: 15 June 2023 / Revised: 31 January 2024 / Accepted: 25 March 2024 / Published online: 2 May 2024
© The Author(s) 2024

Abstract The EU Nature Restoration Law (NRL) is critical for the restoration of degraded ecosystems and active afforestation of degraded peatlands has been suggested as a restoration measure under the NRL. Here, we discuss the current state of scientific evidence on the climate mitigation effects of peatlands under forestry. Afforestation of drained peatlands without restoring their hydrology does not fully restore ecosystem functions. Evidence on long-term climate benefits is lacking and it is unclear whether CO₂ sequestration of forest on drained peatland can offset the carbon loss from the peat over the long-term. While afforestation may offer short-term gains in certain cases, it compromises the sustainability of peatland carbon storage. Thus, active afforestation of drained peatlands is not a viable option for climate mitigation under the EU Nature Restoration Law and might even impede future rewetting/restoration efforts. Instead, restoring hydrological conditions through rewetting is crucial for effective peatland restoration.

Keywords Carbon storage · GHG emissions · Nature based solutions · Nature restoration law · Peatland forestry · Peatland restoration

INTRODUCTION

The EU Nature Restoration Law is critical for the restoration of degraded ecosystems and the provision of climate protection, as clearly shown by the most recent IPCC report (IPCC AR6 SYR 2023). The carbon dioxide (CO₂) sinks necessary to reach climate neutrality and then net cooling during the second half of this century

heavily rely on the land use sector (LULUCF), because improved land stewardship is the most mature CO₂ removal method (e.g. *ibid.*, Field and Mach 2017). However, sinks should not be used to compensate for avoidable sources and emission reduction remains the utmost priority because the sinks cannot—by far—compensate for the large anthropogenic emissions, which urgently need “aggressive and rapid greenhouse gas emission reduction in all sectors of the economy” (Seddon et al. 2021).

Several EU member states pursue the recognition of active afforestation of drained and degraded peatlands (without rewetting) as a measure under the Nature Restoration Law (NRL). This is, however, problematic from a scientific perspective. Firstly, afforestation of drained peatlands, while keeping them drained, will not restore the peatland ecosystem with its flora, fauna and functions. Secondly, as long as a peatland remains drained, it will degrade further, contribute to climate warming through high emissions of CO₂ and nitrous oxide, and downstream systems may be severely polluted with nutrients and dissolved organic matter (Zak and McInnes 2022). Typically, in forested northern peatlands, much more carbon is stored in the peat (22.6–66.0 kg m⁻²) than in the forest biomass (2.8–5.7 kg m⁻²) (Beaulne et al. 2021). Long-term carbon losses from the drained peatland will likely be larger than the amount of carbon stored in the forest biomass (Dunn and Freeman 2011; Makrickas et al 2023). Carbon will be released to the atmosphere as CO₂ when the trees or the manufactured timber products reach the end of their life cycle. Actions focussed on a single ecosystem service too often result in adverse outcomes for the ecosystem as a whole.

Presently, the claim that afforestation on drained peatlands could be beneficial for climate change mitigation in the long-term has to be questioned. In most cases, CO₂ release from peat soil degradation will likely exceed carbon sequestration in the forest biomass when full growth cycles are considered, as was also concluded by the IPCC in the 2013 Wetlands Supplement (IPCC 2014). In contrast, ecosystem-scale flux measurements show that rewetting/restoration¹ of forestry-drained peatlands can reduce soil CO₂ emissions and even restore the CO₂ sink function within a few years/decades (Hambley et al. 2019). A comprehensive assessment must cover the entire land use cycle—from site preparation to sowing or planting, growth of the biomass, thinning or ditch cleaning, through to harvest, the fate of the biomass (whether used for long-lived products or not) and the fallow time before renewed site preparation. For cropping agriculture, this cycle commonly takes in a single year, while in forestry it takes much longer. Longer, comprehensive greenhouse gas monitoring studies are currently only available from the boreal region and even here, the authors call for longer-term studies that include the entire life cycle (e.g., Bjarnadottir et al. 2021). Such studies do not exist to date and so we can only approach the true climate balance of peatland forestry by using space-for-time substitution and stitching together studies that cover different stages of the forestry life cycle.

Here, we review the relevant literature and discuss the role of peatlands in relation to the climate with respect to forestry-drained peatlands in particular. We identify knowledge gaps and suggest future research that will enable better knowledge of the climate effect of peatland forestry.

PEATLANDS AND CLIMATE

A peatland is an area with a naturally accumulated layer of peat at the surface. Peat is a sedentary material consisting of at least 30% (dry mass) of dead organic material. Plants absorb CO₂ and store carbon in their biomass. When they die, they are decomposed and the CO₂ is released again. In mires—peatlands that actively accumulate peat²—water

¹ *Rewetting* and *restoring/restoration* are often used interchangeably but they are not. *Rewetting* describes the deliberate action of raising the water table on drained soils to re-establish water-saturated conditions. In contrast, *restoration* refers to the full re-establishment of all ecosystem functions that cannot be done directly but only be aimed at facilitating measures, such as rewetting, removal of degraded topsoil, and re-introduction of mire-typical vegetation, etc. See the IPCC Wetlands Supplement (IPCC 2014) for a profound discussion of this terminology.

² Definitions based on resolution VIII.17 “Guidelines for Global Action on Peatlands” https://www.ramsar.org/sites/default/files/documents/pdf/res/key_res_viii_17_e.pdf, IMCG & IPS Wise Use Guidelines (Joosten & Clarke 2002), and “Mires and Peatlands of Europe” (Joosten et al. 2017).

saturation of the soil effectively excludes oxygen, thereby inhibiting the full decomposition of the plant litter, which then accumulates as peat. In this way, peatlands have sequestered huge amounts of carbon over millennia. Globally, peatlands store approximately 600 Gt of carbon (Yu et al. 2010; UNEP 2022), which is more than is contained in global forest above-ground biomass (Santoro et al. 2021), and have cooled the planet by approximately 0.6 °C over the past 10,000 years (Frolking and Roulet 2007; Joosten et al. 2016). Forests and peatlands are fundamentally different in terms of carbon cycling over time, in that pristine mature forests are generally in balance (although this view has also been challenged by, e.g. Luysaert et al. (2008)); whereas, peatlands continue to accumulate carbon, year after year.

While mires sequester carbon from the atmosphere, incomplete decomposition under water-saturated oxygen-free conditions results in the production of methane (CH₄). The amount of CH₄ released from pristine, wet peatlands varies strongly depending on environmental conditions such as pH, temperature and vegetation (e.g. Lai 2009). Methane is a short-lived greenhouse gas (GHG) and stays in the atmosphere, on average, for less than 12 years. Thus, given steady emissions of CH₄, a dynamic equilibrium will establish over time in which in a certain year the same amount of CH₄ will disappear from the atmosphere as is added from the peatland, and the CH₄ concentration in the atmosphere and the climate impact do not increase any further (Frolking and Roulet 2007). Pristine, undrained peatlands almost always release CH₄, but the net uptake of CO₂ overcompensates for the CH₄ losses in the long-term. In mires, i.e. wet peat-forming peatlands, formation and emissions of nitrous oxide (N₂O, a potent greenhouse gas) are negligible.

When peatlands are drained, the upper soil layers are no longer water-saturated, oxygen enters the peat, and decomposition of organic matter becomes much more efficient, leading to mineralisation of the peat and, thus, high CO₂ (Ojanen et al. 2010; Jovani-Sancho et al. 2018) and N₂O emissions (Klemedtsson et al. 2005; IPCC 2014; Leppelt et al. 2014; Minkkinen et al. 2020). In contrast, CH₄ production and emissions generally decrease because of water table drawdown; while, drainage ditches may remain a major source of CH₄ emissions (Minkkinen et al. 1997; Köhn et al. 2021; Rissanen et al. 2023). Draining reduces soil CH₄ emissions but increases soil CO₂ and N₂O emissions, as well as CH₄ emissions from drainage infrastructure such as ditches. In the case of forestry, drainage also increases tree stand carbon stock, until the stand is cut. This may lead to short-term cooling in the boreal climate zone, but in most cases, the long-term effect will be warming (Laine et al. 1996; Ojanen and Minkkinen 2020).

In order to determine the climate effect of rewetted peatlands, we need to compare CO₂, CH₄ and N₂O emissions, and lateral losses of carbon and nitrogen both in drained and rewetted situations. Rewetting is always a choice between continued emissions of long-lived GHGs (CO₂ and N₂O) versus emissions of a short-lived GHG (CH₄). In the short-term, rewetting will not result in net cooling because of increased CH₄ emissions, but will in the long-term (decades to centuries) (Wilson et al. 2016, 2022; Günther et al. 2020; Ojanen and Minkkinen 2020). However in most cases, rewetting peatlands will pay off immediately, or after a very short time period, *i.e.*, total radiative forcing is lower than in the drained state (Günther et al. 2020; Tanneberger et al. 2021b). Re-introduction of vegetation on cutover bogs (Rocheffort et al. 2003; González and Rocheffort 2014), but also after topsoil removal on formerly drained grassland on bog peat (Rosinski et al. 2021) can speed-up restoration of the GHG sink function after rewetting (Nugent et al. 2018, 2019; Huth et al. 2022).

FORESTRY ON PEATLANDS

Peatland forestry is common in the boreal zone, but also occurs across the temperate climate zone. Globally, approximately 12 million hectares (Mha) of peatlands have been drained for forestry (Minkkinen et al. 2023). This represents approximately 3% of the global peatland area (ca. 440 Mha, Yu et al. 2010). Most of the area under peatland forest is situated in Fennoscandia and Russia, where over 10 Mha of peatlands have been drained for forestry (*ibid.*). In Canada and the United States, forestry is also practised on undrained peatlands.

In Europe, peatland forestry is mainly found in the north (*i.e.* Finland, Sweden, and Norway), but is also of national importance in the Baltic countries, United Kingdom, Ireland, Poland and Germany (see Fig. 1, data for non-EU countries are not included). Typically, peatlands used for forestry are drained, which leads to a simultaneous increase in CO₂ and N₂O emissions through peat decomposition (see above) and CO₂ sequestration through the growing tree stand; while, the drainage ditches may still emit considerable amounts of CH₄.

CLIMATE IMPACT OF PEATLAND FORESTRY

Although soil CO₂ emissions increase after drainage, several studies on drained boreal peatland forests, made with micrometeorological or combined chamber-efflux-litter-production-methods, suggest that carbon sequestration in the tree biomass can exceed the carbon loss from the decomposition of the peat (Lindroth et al. 2007; Meyer

et al. 2013; Ojanen et al. 2013; Uri et al. 2017; Minkkinen et al. 2018; Bjarnadottir et al. 2021). In most cases, however, soil C stocks decrease over time, which is the deciding factor when whole rotation climate impacts are considered. Nutrient-poor sites in the boreal zone may accumulate carbon in the soils (Ojanen et al. 2013), but in the absence of a high water table, the fate of this carbon is unclear over a production cycle.

Measuring greenhouse gas fluxes in peatland forests is challenging

The most common way to measure greenhouse gas fluxes in treeless peatlands has been to place airtight chambers on the surface and to measure the change in the concentration of gases inside the chamber. This commonly applied technique cannot be used in a forest stand as mature trees typically cannot fit inside the chambers. Therefore, the soil carbon balance is estimated by subtracting measured litter production from heterotrophic soil respiration (e.g. Ojanen et al. 2012, 2013; Jovani-Sancho et al. 2021; Uri et al. 2017) where the latter has been measured from trenched plots in which plants and tree roots have been excluded. Simply placing chambers on the forest soil will not provide reliable measurements of fluxes from soil degradation, because the roots of the trees also emit CO₂ (*i.e.* autotrophic soil respiration). Intricate chamber set ups are required to distinguish between emissions from the soil (*i.e.* heterotrophic soil respiration) and from the living tree roots (*i.e.* autotrophic respiration) (Mäkiranta et al. 2008; Hermans et al. 2022).

The eddy covariance technique (EC), which uses fast measuring gas analysers, requires large flat and homogeneous areas, which are also difficult to find because forestry areas on peatlands are often organised in fairly small blocks. EC is the standard method for ecosystem-level measurements and has a typical uncertainty between 5 and 15% (Burba 2022). The method also allows for the estimation of the soil carbon sink/source by subtracting the modelled biomass increment from the measured net ecosystem exchange. Other soil carbon balance estimation methods include the estimation of soil subsidence through pollen or carbon isotope profiles or by consecutive thickness measurements (Minkkinen et al. 1999; Hooijer et al. 2012; Simola et al. 2012; Sloan et al. 2019). These integrate longer time periods. Obtaining accurate estimates for these carbon balance estimation methods is, thus, challenging.

The above-mentioned studies consider forestry on drained peatlands, but these are based on natural tree stands in the boreal zone. In the temperate zone, sites have more often been drained for agriculture or peat extraction and only later been afforested. Most of the studies do not describe the situation after afforestation of agricultural

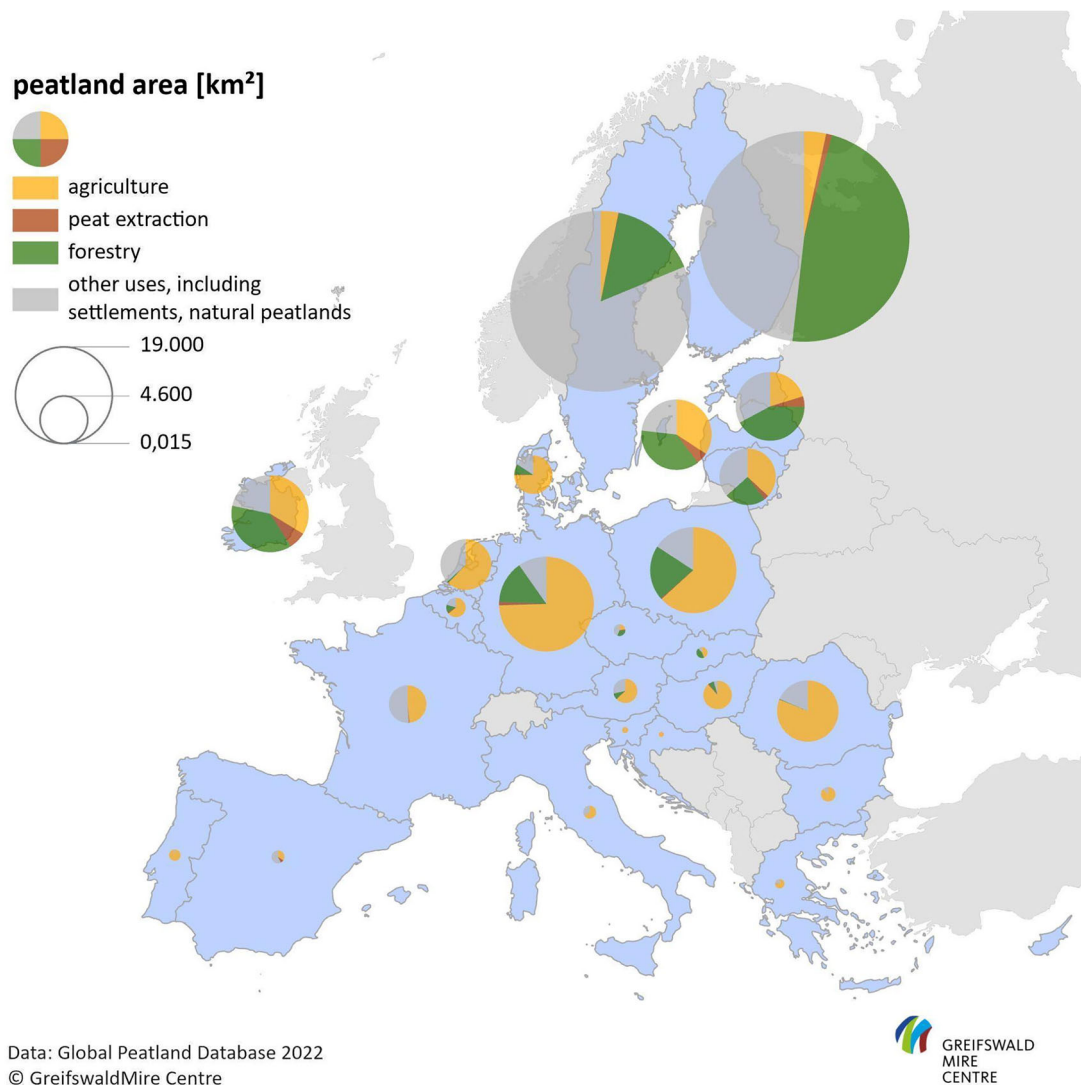


Fig. 1 Areal share of peatlands under agriculture, peat extraction, forestry, and other uses in countries of the European Union. Colours refer to different land use types, and the size of the circles reflects total peatland area

fields or cutover peatlands, yet this difference in soil management history may lead to different outcomes (Jauhiainen et al. 2023). In addition, the above-mentioned gas exchange studies only give a temporary GHG balance for the study period. *They do not consider the whole forestry cycle, which includes harvesting of the wood (i.e. the removal of sequestered biomass C), decomposition of wood products, and the time needed for stand regeneration.* Harvested sites, especially clear-cut sites, are large carbon sources (Korkiakoski et al. 2019, 2023) until a new stand has regenerated. In addition, only a small proportion of wood products is long-lived as most of the carbon in wood products is lost to the atmosphere in a few years after cuttings (Soimakallio et al. 2016).

State of knowledge on greenhouse gas exchange in peatland forests

A recent study from Iceland (Bjarnadottir et al. 2021) showed no warming effects of peatland forestry compared to rewetted or wet peatlands. The study area, a poorly drained site, was afforested with a very productive species (Black cottonwood, *Populus trichocarpa*). According to the authors, only further long-term studies and life-cycle assessments will show whether forestry on drained peatlands can really be more climate friendly than wet and healthy peatlands. A recent meta-analysis examining the climate effects of forestry on *shallow* organic soils (< 40–50 cm peat depth) in Scotland showed no warming climate effect

(Vanguelova et al. 2018). However, meta-analyses that explore the effects of forestry on *deep* peat soils in the temperate climate region show considerable net emissions of CO₂ to the atmosphere, at least when the whole life-cycle is considered (Hommeltenberg et al. 2014; Jovani-Sancho et al. 2021). The latter finding confirms the emission factors derived in the 2013 IPCC Wetland Supplement (IPCC 2014). The considerably lower figures for carbon loss from the soil reported in Hermans et al. (2022) show that there can be strong variation across sites, which would suggest that more research on the matter is needed. With respect to the harvesting stage of peatland forestry, selective cutting instead of clear-cutting can lower GHG emissions in a forestry-drained peatland in the boreal climate zone (Korkiakoski et al. 2023). Although the site with partial harvest studied by Korkiakoski et al. (2023) transformed into a CO₂ sink five years after harvest, peat decomposition continued, releasing almost the same amount of carbon into the atmosphere as was fixed by the trees. Most studies in drained peatland forests show similar results: the ecosystem may be a C sink; whereas, the soil is a C source. Therefore, production forestry, where biomass C is harvested and rapidly lost back to the atmosphere (Soimakallio et al. 2016), will likely result in net C losses in the long-term.

A recent synthesis of site-specific greenhouse gas emissions from drained organic forest soils suggests new emission factors for boreal and cool temperate regions (Jauhiainen et al. 2023). Only one of the derived emission factors, the one for the site type “afforested after peat extraction”, suggests a minor CO₂ sink (-86.12 ± 247.34 (SD) g m⁻² a⁻¹). It is based on only one study (featuring 6 sites) and the emission factor for N₂O for the same site type is actually quite similar but with opposite sign (95.55 ± 32.76 (SD) g m⁻² a⁻¹) when transformed to CO₂ equivalents (according to IPCC AR6) suggesting overall climate neutrality during the growth phase of the forest. All other emission factors for the discussed site types suggest peatland forests to be overall sources of CO₂ equivalent emissions to the atmosphere although some categories (e.g. low productivity nutrient-poor sites in the boreal or typical productivity sites in the temperate region (independent of nutrient status)) come out with lower emission factors compared to the IPCC 2014 Tier 1 approach.

Thus, none of the studies discussed above provides a basis to include active afforestation on drained peatlands, especially if managed for production forestry, as a viable option under the NRL.

Discussion of findings of recent studies lacking scientific rigour

Some recent studies from Latvia do seem to support the idea that afforestation of drained peatlands could be better for the climate than rewetting. However, these studies are

inconclusive, have major flaws and biases, and cannot be verified and validated because the methods used are error-prone and descriptions often lack clarity. For instance, Samariks et al. (2023) claim to show that afforestation of peat extraction sites can result in net carbon removals. However, they did not measure all elements of the carbon cycle and failed to clearly distinguish between soil emissions and emissions from tree roots. Instead of analysing, they simply *assumed* that the soil fluxes made up less than half of the measured total flux, independent of changes in management or site conditions, which is unrealistic because the share of soil flux to the total ecosystem flux varies widely (Ojanen et al. 2010). Moreover, the appropriate comparison would have been with a rewetted peat extraction site. Further, after peat extraction, any rehabilitation measures including plant establishment will likely result in net carbon removals because in the first years the biomass stock will build up. Bārdule et al. (2022) suggested that wet peatlands do not achieve lower emissions than drained peatlands. However, they measured only once per month over a period of only four months, during only one vegetation period. Their experimental set up allowed only the emitted CO₂ flux from the system (soil and litter degradation plus plant respiration) to be measured, but not the sequestration of CO₂ from the atmosphere during photosynthesis. Moreover, they neglected to account for the fluvial carbon export from the drained sites.

Butlers et al. (2021) reported larger N₂O and CH₄ emissions from ‘naturally wet’ sites than from ‘drained’ forests. These findings are not surprising given that the ‘drained’ site in the study had water tables deeper than 60 cm below the soil surface in summer. Again, a full GHG balance can only be assessed when CO₂ exchange is included as well. Butlers et al. (2022a) claimed that CO₂ emissions from ‘naturally wet’, nutrient-rich organic forest soils can be larger than those from drained sites but they did not include photosynthesis by ground vegetation in their study and did not quantify CO₂ release from the tree roots, thus, failing to describe net-CO₂ exchange appropriately. Without inclusion of the contribution of trees and without a full life cycle assessment, no sensible conclusions about the climate effect of wet vs. drained forested peatlands can be drawn.

Butlers et al. (2022a) attempted to obtain a better understanding of the whole GHG balance by looking at different stages of the harvest cycle and even including the input of litter. Again, the same error-prone methods were used. No distinction is made between root- and soil-derived emissions in the measurements. Instead a regression equation is used, which indicates that slightly more than half of the measured flux is related to decomposition of litter and soil. The equation employed presents a broad relationship that may be helpful to constrain large scale

estimates, but was not made to infer site-specific flux values, as was stressed by the original authors of the equation (Bond-Lamberty and Wang 2004). Again, the conclusions are based on limited measurements. They fall far short of the full life-cycle assessment that is essential if reliable data for the effects of forest growth on drained peatlands are to be compared with the situation in rewetted or pristine peatlands. In addition, there were no measurements conducted in intact or rewetted peatlands to provide an appropriate baseline for comparison. Thus, the study results are unsuitable to support far reaching generalisations with regard to afforestation of peatlands as viable options to achieve climate goals under the NRL.

The need for full production cycle analyses

Most importantly, however, the felling of trees and the subsequent fate of the carbon sequestered in the wood needs to be considered (Ciais et al. 2008). As little as 50% of the actual tree biomass may be extracted during harvest; the remainder is left to decompose on site and within a few years returns as CO₂ to the atmosphere (Korkiakoski et al. 2019; Leturcq 2020). After a tree is felled, much of its carbon can be stored in wood products. The processing of raw wood for product is estimated to produce (1) waste wood residues and (2) short-lived products (bioenergy, pellets, and pulp and paper (Jasinevičius 2018) of ~40–60% being subject to fast carbon release (Sokka et al. 2015). Yet a simple carbon balance does not tell the whole story; unlike the carbon stock in soil and peat, not everything made out of wood is climate neutral (Leturcq 2020). As a rule, for a long-lasting product made out of 80-year old wood to be climate cooling, the wood should not be discarded and burnt for at least 40 years after harvest. A product made from 40-year old wood would need to remain for at least 20 years after harvest (Guest et al. 2013; Galimshina et al. 2022). Long-lived harvested wood products are actually quite rare, and harvesting does reduce the total amount of carbon stored in the forest (Soimakallio et al. 2022). In assessing the GHG balance of peatland forestry, complete harvest cycles should be taken into account. Such data are simply absent at the moment.

Since trees grow slowly, no measurements of full growth cycles are yet available and results that span longer time periods are derived from the investigation of chronosequences. Certainly, more chronosequence work is needed, but measurements must be made over multiple years so that variations in weather and other environmental conditions can be integrated into the models. As Vanguelova et al. (2018) have expressed: “There is a clear need for long-term studies using different planting ages (chronosequence studies) to ensure robust results when evaluating the impacts of afforestation and restocking on soil carbon

stocks, as short-term impact studies are likely to provide misleading conclusions.”

Overall, Finland’s land use sector, for instance, seems to have gradually transitioned from being a CO₂ sink to a source (Statistics Finland 2022b) driven by increased demand for wood products, slower increase in growing stock, and rising emissions from soil organic matter and litter in drained peat-based forest soils. Siljander et al. (2022) have suggested that the fastest way to strengthen carbon sinks in Finland is to reduce logging, and the Finnish Nature Panel has recommended, among other things, the rewetting and restoration of wetlands and peatlands (Lång et al. 2022).

Additional possible effects of drained peatland forestry

Peatland forestry on drained sites is more prone to wildfires (Kohlenberg et al. 2018), which will become more frequent and severe in times of climate change with more frequent and more intense droughts in the boreal zone (Walker et al. 2019). Boreal forests in North America have turned from a net sink to a net source of GHG in recent years (Zhao et al. 2021), primarily due to more frequent and more severe fires (Zheng et al. 2023). In addition to the carbon loss from burnt wood, as well as substantial carbon losses from burnt and burning peat layers, should be considered, including the waterborne carbon losses (Liu et al. 2023). In countries with a relatively high density of forest roads, such as Finland, the severity of forest fires on peatland could be increased. This is because large drained peatland areas with forest often have a much lower density of roads compared to areas with mineral ground, thereby making it more challenging to control fires in these peatland regions.

In addition to GHG exchange, the change in albedo and the release of aerosols, together with the lateral exchange of carbon and nitrogen, all add to the total climate effect of ecosystems (Billett et al. 2010). Increased tree cover decreases the albedo effect compared to a treeless mire (Lohila et al. 2010), which leads to local warming (Gao et al. 2014). However, forests are also large sources of biogenic volatile organic compounds (BVOC) and thus may have a considerable cooling impact on the climate (Tunved et al. 2006). In the boreal zone, this impact is similar in magnitude, but opposite to that of the albedo (Kalliokoski et al. 2020).

Aside from site-related atmospheric impacts, forestry on peatland may also have negative impacts on water storage capacity, water quality and nutrients runoff, including loss of organic matter via fluvial pathways, which is subsequently mineralised and the carbon partially returned to the atmosphere (Evans et al. 2016). Rewetting of drained peatlands can also lead to considerable amounts of nitrogen

and phosphorus leaching (e.g., Koskinen et al. 2017) but the nutrient-sink function can be rapidly recovered provided further restoration management is implemented (Zak and McInnes 2022). The loss in water storage capacity due to the loss of pore space caused by drainage can manifest itself in greater variations in stream flow and water quality for downstream aquatic ecosystems (Flynn et al. 2021). Intense rainfall events are predicted to increase under climate warming, which can cause mid-term flooding leading to the die-back of trees caused by increased hydrological instability. Indeed, more research to evaluate the trade-off values of wood production, carbon sequestration and emissions, and water storage of natural, drained, and rewetted peatlands like it has been recently published by Makrickas et al. (2023) is urgently required (Manton et al. 2021).

CONCLUSIONS

The most recent IPCC report (IPCC AR6 SYR 2023) outlines in clear language that we must come to grips with proper natural climate solutions since they are paramount to avoid the gravest consequences of climate change and global warming. The Nature Restoration Law (NRL) proposed by the European Commission is a key component to unlock the climate mitigation potential of degraded ecosystems. ***The many open questions and lack of evidence for overall climate benefits of active afforestation on peatlands prohibit its inclusion as a viable climate change mitigation measure in the NRL.*** Moreover, the NRL should foster true natural ecosystems wherever possible, particularly where those are demonstrably carbon capture systems. A forest that can only grow when the peat below the trees is drained does not comply with this requirement. ***Afforestation of drained peatlands is not restoration. We cannot restore peatland ecosystems, their flora, their fauna, their functions, by afforestation. The only solution to restore drained peatlands is rewetting.*** The re-introduction of natural mire vegetation can potentially speed-up the restoration process. If trees belong to such an ecosystem, they will regenerate naturally.

Funding Open Access funding enabled and organized by Projekt DEAL. Christian Fritz was supported by WET HORIZONS GAP-101056848.

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the

source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

REFERENCES

- Artz, R.R.E., S.J. Chapman, M. Saunders, C.D. Evans, and R.B. Matthews. 2013. Comment on “Soil CO₂, CH₄ and N₂O fluxes from an afforested lowland raised peat bog in Scotland: implications for drainage and restoration” by Yamulki et al. *Biogeosciences* 10: 7623–7630.
- Bārdule, A., L. Gerra-Inohosa, I. Kļaviņš, Z. Kļaviņa, K. Bitenieks, A. Butlers, A. Lazdiņš, and Z. Lībiete. 2022. Variation in the mercury concentrations and greenhouse gas emissions of pristine and managed hemiboreal peatlands. *Land* 11: 1414.
- Beaulne, J., M. Garneau, G. Magnan, and É. Boucher. 2021. Peat deposits store more carbon than trees in forested peatlands of the boreal biome. *Scientific Reports* 11: 2657.
- Billett, M.F., D.J. Charman, J.M. Clark, C.D. Evans, M.G. Evans, N.J. Ostle, F. Worrall, A. Burden, et al. 2010. Carbon balance of UK peatlands: Current state of knowledge and future research challenges. *Climate Research* 45: 13–29.
- Bjarnadottir, B., G.A. Sungur, B.D. Sigurdsson, B.T. Kjartansson, H. Oskarsson, E.S. Oddsdottir, G.E. Gunnarsdottir, and A. Black. 2021. Carbon and water balance of an afforested shallow drained peatland in Iceland. *Forest Ecology and Management* 482: 118861.
- Bond-Lamberty, B., and C. Wang. 2004. Gower ST (2004) A global relationship between the heterotrophic and autotrophic components of soil respiration? *Global Change Biology* 10: 1756–1766.
- Burba, G. 2022. *Eddy Covariance Method for Scientific, Regulatory, and Commercial Applications*. Lincoln, Nebraska: LI-COR Biosciences.
- Butlers, A., and A. Lazdiņš. 2022. Case study on greenhouse gas (GHG) fluxes from flooded former peat extraction fields in central part of Latvia. *Research for Rural Development* 37: 44–49.
- Butlers, A., A. Lazdiņš, S. Kalēja, and A. Bārdule. 2022a. Carbon budget of undrained and drained nutrient-rich organic forest soil. *Forests* 13: 1790.
- Butlers, A., A. Bārdule, G. Spalva, and E. Muižnieks. 2021. N₂O and CH₄ emissions from naturally wet and drained nutrient-rich organic forest soils. In *Proceedings of the International Scientific Conference “Rural Development”* 196–200.
- Butlers, A., G. Spalva, I. Licite, and D. Purvina. 2022a. Carbon dioxide (CO₂) emissions from naturally wet and drained nutrient-rich organic forest soils. In *Proceedings of the 21st International Scientific Conference ‘Engineering for Rural Development’*, Jelgava, Latvia 25–27.
- Ciais, P., M.J. Schelhaas, S. Zaehle, S.L. Piao, A. Cescatti, J. Liski, S. Luyssaert, G. Le-Maire, et al. 2008. Carbon accumulation in European forests. *Nature Geoscience* 1: 425–429.
- Davidson, S.J., E.M. Goud, C. Franklin, S.E. Nielsen, and M. Strack. 2020. Seismic line disturbance alters soil physical and chemical properties across boreal forest and peatland soils. *Frontiers in Earth Sciences* 8: 281.
- Dunn, C., and C. Freeman. 2011. Peatlands: Our greatest source of carbon credits? *Carbon Management* 2: 289–301.

- Field, C.B., and K.J. Mach. 2017. Rightsizing carbon dioxide removal. *Science* 356: 706–707.
- Flynn, R., F. Mackin, C. McVeigh, and F. Renou-Wilson. 2021. Impacts of mature forestry plantation on blanket peatland runoff regime and water quality. *Hydrological Processes* 36: e14494.
- Frolking, S., and N.T. Roulet. 2007. Holocene radiative forcing impact of northern peatland carbon accumulation and methane emissions. *Global Change Biology* 13: 1079–1088.
- Galimshina, A., M. Moustapha, A. Hollberg, P. Padey, S. Lasvaux, B. Sudret, and G. Habert. 2022. Bio-based materials as a robust solution for building renovation: A case study. *Applied Energy* 316: 119102.
- Gao, Y., T. Markkanen, L. Backman, H.M. Henttonen, J.-P. Pietikäinen, H.M. Mäkelä, and A. Laaksonen. 2014. Biogeophysical impacts of peatland forestation on regional climate changes in Finland. *Biogeosciences* 11: 7251–7267.
- González, E., and L. Rochefort. 2014. Drivers of success in 53 cutover bogs restored by a moss layer transfer technique. *Ecological Engineering* 68: 279–290.
- Guest, G., F. Cherubini, and A.H. Strømman. 2013. Global warming potential of carbon dioxide emissions from biomass stored in the anthroposphere and used for bioenergy at end of life. *Journal of Industrial Ecology* 17: 20–30.
- Günther, A., A. Barthelmes, V. Huth, H. Joosten, G. Jurasinski, F. Koebisch, and J. Couwenberg. 2020. Prompt rewetting of drained peatlands reduces climate warming despite methane emissions. *Nature Communications* 11: 1644.
- Hambley, G., R. Andersen, P. Levy, M. Saunders, N.R. Cowie, Y.A. Teh, and T.C. Hill. 2019. Net ecosystem exchange from two formerly afforested peatlands undergoing restoration in the Flow Country of northern Scotland. *Mires and Peat* 2018 (19): 05.
- He, H., P.E. Jansson, M. Svensson, J. Björklund, L. Tarvainen, L. Klemedtsson, and Å. Kasimir. 2016. Forests on drained agricultural peatland are potentially large sources of greenhouse gases – insights from a full rotation period simulation. *Biogeosciences* 13: 2305–2318.
- Hermans, R., R. McKenzie, R. Andersen, Y.A. Teh, N. Cowie, and J.A. Subke. 2022. Net soil carbon balance in afforested peatlands and separating autotrophic and heterotrophic soil CO₂ effluxes. *Biogeosciences* 19: 313–327.
- Hommelntenberg, J., M. Mauder, M. Drösler, K. Heidbach, P. Werle, and H.P. Schmid. 2014. Ecosystem scale methane fluxes in a natural temperate bog-pine forest in southern Germany. *Agricultural and Forest Meteorology* 198: 273–284.
- Hooijer, A., S. Page, J. Jauhiainen, W.A. Lee, X.X. Lu, A. Idris, and G. Anshari. 2012. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences* 9: 1053–1071.
- Huth, V., A. Günther, A. Bartel, C. Gutekunst, S. Heinze, B. Hofer, O. Jacobs, F. Koebisch, et al. 2022. The climate benefits of topsoil removal and Sphagnum introduction in raised bog restoration. *Restoration Ecology* 30: e13490.
- IPCC AR6 SYR. 2023. *Synthesis report of the IPCC sixth assessment report (AR6)—Summary for Policymakers*
- IPCC. 2014. 2013 *Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. IPCC, Switzerland
- Jasinevičius, G., M. Lindner, E. Cienciala, and M. Tykkyläinen. 2018. Carbon accounting in harvested wood products: Assessment using material flow analysis resulting in larger pools compared to the IPCC default method. *Journal of Industrial Ecology* 22: 121–131.
- Jauhiainen, J., J. Heikkinen, N. Clarke, H. He, L. Dalsgaard, K. Minkkinen, P. Ojanen, L. Vesterdal, et al. 2023. Reviews and syntheses: Greenhouse gas emissions from drained organic forest soils – synthesizing data for site-specific emission factors for boreal and cool temperate regions. *Biogeosciences* 20: 4819–4839.
- Joosten, H., A. Sirin, J. Couwenberg, J. Laine, and P. Smith. 2016. The role of peatlands in climate regulation. In *Peatland Restoration and Ecosystem Services: Science, Policy and Practice*, ed. A. Bonn, T. Allot, M. Evans, H. Joosten, and R. Stoneman, 63–76. Cambridge: Cambridge University Press.
- Joosten, H., and D. Clarke. 2002. *Wise use of mires and peatlands*. International Mire Conservation Group and International Peat Society, 304
- Jovani-Sancho, A.J., T. Cummins, and K.A. Byrne. 2021. Soil carbon balance of afforested peatlands in the maritime temperate climatic zone. *Global Change Biology* 27: 3681–3698.
- Kalliokoski, T., J. Bäck, M. Boy, M. Kulmala, N. Kuusinen, A. Mäkelä, K. Minkkinen, F. Minunno, et al. 2020. Mitigation impact of different harvest scenarios of Finnish forests that account for albedo, aerosols and trade-offs of carbon sequestration and avoided emissions. *Frontiers in Forests and Global Change* 3: 562044.
- Kasimir, Å., H. He, J. Coria, and A. Nordén. 2018. Land use of drained peatlands: Greenhouse gas fluxes, plant production, and economics. *Global Change Biology* 24: 3302–3316.
- Kasimir, Å., H. He, P.E. Jansson, A. Lohila, and K. Minkkinen. 2021. Mosses are important for soil carbon sequestration in forested peatlands. *Frontiers in Environmental Science* 9: 680430.
- Klemedtsson, L., K. von Arnold, P. Weslien, and P. Gundersen. 2005. Soil CN ratio as a scalar parameter to predict nitrous oxide emissions. *Global Change Biology* 11: 1142–1147.
- Kohlenberg, A.J., M.R. Turetsky, D.K. Thompson, B.A. Branfireun, and C.P.J. Mitchell. 2018. Controls on boreal peat combustion and resulting emissions of carbon and mercury. *Environmental Research Letters* 13: 035005.
- Köhn, D., C. Welpelo, A. Günther, and G. Jurasinski. 2021. Drainage ditches contribute considerably to the CH₄ budget of a drained and a rewetted temperate fen. *Wetlands* 41: 71.
- Korkiakoski, M., J.P. Tuovinen, T. Penttilä, S. Sarkkola, P. Ojanen, K. Minkkinen, J. Rainne, T. Laurila, et al. 2019. Greenhouse gas and energy fluxes in a boreal peatland forest after clear-cutting. *Biogeosciences* 16: 3703–3723.
- Korkiakoski, M., P. Ojanen, T. Penttilä, K. Minkkinen, S. Sarkkola, J. Rainne, T. Laurila, and A. Lohila. 2020. Impact of partial harvest on CH₄ and N₂O balances of a drained boreal peatland forest. *Agricultural and Forest Meteorology* 295: 108168.
- Korkiakoski, M., P. Ojanen, J.P. Tuovinen, K. Minkkinen, O. Nevalainen, T. Penttilä, M. Aurela, T. Laurila, et al. 2023. Partial cutting of a boreal nutrient-rich peatland forest causes radically less short-term on-site CO₂ emissions than clear-cutting. *Agricultural and Forest Meteorology* 332: 109361.
- Koskinen, M., T. Tahvanainen, S. Sarkkola, M.W. Menberu, A. Laurén, T. Sallantausta, H. Marttila, A.-K. Ronkanen, et al. 2017. Restoration of nutrient-rich forestry-drained peatlands poses a risk for high exports of dissolved organic carbon, nitrogen, and phosphorus. *Science of the Total Environment* 586: 858–869.
- Lai, D.Y.F. 2009. Methane dynamics in northern peatlands: A review. *Pedosphere* 19: 409–421.
- Lång, K., L. Aro, A. Assmuth, E. Haltia, S. Hellsten, T. Larmola, H. Lempiäinen, L. Lindfors, et al. 2022. Turvemaiden käytön vaihtoehdot hiilineutraalissa Suomessa (In Finnish). *Suomen ilmastopaneelin raportti2/2022*, Helsinki, Finland.
- Lepilinen, D., A. Laurén, J. Uusitalo, H. Fritze, R. Laiho, B. Kimura, and E.-E. Tuittila. 2021. Response of vegetation and soil biological properties to soil deformation in logging trails of drained boreal peatland forests. *Canadian Journal of Forest Research* 52: 511–526.
- Leppelt, T., R. Dechow, S. Gebbert, A. Freibauer, A. Lohila, J. Augustin, M. Drösler, S. Fiedler, et al. 2014. Nitrous oxide

- emission budgets and land-use-driven hotspots for organic soils in Europe. *Biogeosciences* 11: 6595–6612.
- Leturcq, P. 2020. GHG displacement factors of harvested wood products: The myth of substitution. *Scientific Reports* 10: 20752.
- Lindroth, A., M. Lund, M. Nilsson, M. Aurela, T.R. Christensen, T. Laurila, J. Rinne, T. Riutta, et al. 2007. Environmental controls on the CO₂ exchange in north European mires. *Tellus B: Chemical and Physical Meteorology* 59: 812–825.
- Lindsay, R., A. Ifo, L. Cole, L. Montanarella, and M. Nuutinen. 2019. Peatlands: The challenge of mapping the world's invisible stores of carbon and water. *Unasylva* 70: 46–57.
- Liu, H., D. Zak, N. Zableckis, A. Cossmer, N. Langhammer, B. Meermann, and B. Lennartz. 2023. Water pollution risks by smoldering fires in degraded peatlands. *Science of the Total Environment* 871: 161979.
- Lohila, A., K. Minkkinen, J. Laine, I. Savolainen, J.-P. Tuovinen, L. Korhonen, T. Laurila, H. Tietäväinen, et al. 2010. Forestation of boreal peatlands — impacts of changing albedo and greenhouse gas fluxes on radiative forcing. *Journal of Geophysical Research* 115: G04011.
- Luyssaert, S., E.D. Schulze, A. Börner, A. Knohl, D. Hessenmöller, B.E. Law, P. Ciais, and J. Grace. 2008. Old-growth forests as global carbon sinks. *Nature* 455: 213–215.
- Mäkiranta, P., K. Minkkinen, J. Hytönen, and J. Laine. 2008. Factors causing temporal and spatial variation in heterotrophic and rhizospheric components of soil respiration in afforested organic soil croplands in Finland. *Soil Biology and Biochemistry* 40: 1592–1600.
- Makrickas, E., M. Manton, P. Angelstam, and M. Grygoruk. 2023. Trading wood for water and carbon in peatland forests? Rewetting is worth more than wood production. *Journal of Environmental Management* 341: 117952.
- Manton, M., E. Makrickas, P. Banaszuk, A. Kołos, A. Kamocki, M. Grygoruk, M. Stachowicz, L. Jarašius, et al. 2021. Assessment and spatial planning for peatland conservation and restoration: Europe's Trans-Border Neman River Basin as a Case Study. *Land* 10: 174.
- Meyer, A., L. Tarvainen, A. Nouratpour, R.G. Björk, M. Ernfors, A. Grelle, Å. Kasimir Klemetsson, A. Lindroth, et al. 2013. A fertile peatland forest does not constitute a major greenhouse gas sink. *Biogeosciences* 10: 7739–7758.
- Minkkinen, K., J. Laine, H. Nykänen, and P. Martikainen. 1997. Importance of drainage ditches in emissions of methane from mires drained for forestry. *Canadian Journal of Forest Research* 27: 949–952.
- Minkkinen, K., H. Vasander, S. Jauhiainen, M. Karsisto, and J. Laine. 1999. Post-drainage changes in vegetation composition and carbon balance in Lakkasuo mire, Central Finland. *Plant and Soil* 207: 107–120.
- Minkkinen, K., P. Ojanen, T. Penttilä, M. Aurela, T. Laurila, J.P. Tuovinen, and A. Lohila. 2018. Persistent carbon sink at a boreal drained bog forest. *Biogeosciences* 15: 3603–3624.
- Minkkinen, K., P. Ojanen, M. Koskinen, and T. Penttilä. 2020. Nitrous oxide emissions of undrained, forestry-drained, and rewetted boreal peatlands. *Forest Ecology and Management* 478: 118494.
- Minkkinen, K., B. Bjarnadottir, K.A. Byrne, N. Clarke, J. Jauhiainen, S. Jutras, Å. Kasimir, B. Lafleur, et al. 2023. The impacts of forestry on peatland carbon stocks, greenhouse gas dynamics, and climate. In *Peatlands and Climate Change, 2nd edition – Scientific Facts and Figures for Decision-Makers*, ed. M. Strack, 414. Jyväskylä: International Peatland Society.
- Nugent, K.A., I.B. Strachan, M. Strack, N.T. Roulet, and L. Rochefort. 2018. Multi-year net ecosystem carbon balance of a restored peatland reveals a return to carbon sink. *Global Change Biology* 24: 5751–5768.
- Nugent, K.A., I.B. Strachan, N.T. Roulet, M. Strack, S. Frolking, and M. Helbig. 2019. Prompt active restoration of peatlands substantially reduces climate impact. *Environmental Research Letters* 14: 124030.
- Ojanen, P., and K. Minkkinen. 2020. Rewetting offers rapid climate benefits for tropical and agricultural peatlands but not for forestry-drained peatlands. *Global Biogeochemical Cycles* 34: e2019GB006503.
- Ojanen, P., K. Minkkinen, J. Alm, and T. Penttilä. 2010. Soil–atmosphere CO₂, CH₄ and N₂O fluxes in boreal forestry-drained peatlands. *Forest Ecology and Management* 260: 411–421.
- Ojanen, P., K. Minkkinen, A. Lohila, T. Badorek, and T. Penttilä. 2012. Chamber measured soil respiration: A useful tool for estimating the carbon balance of peatland forest soils? *Forest Ecology and Management* 277: 132–140.
- Ojanen, P., K. Minkkinen, and T. Penttilä. 2013. The current greenhouse gas impact of forestry-drained boreal peatlands. *Forest Ecology and Management* 289: 201–208.
- Poyda, A., T. Reinsch, C. Kluß, R. Loges, and F. Taube. 2016. Greenhouse gas emissions from fen soils used for forage production in northern Germany. *Biogeosciences* 13: 5221–5244.
- Renou-Wilson, F., and E.P. Farrell. 2007. Phosphorus in surface runoff and soil water following fertilization of afforested cutaway peatlands. *Boreal Environment Research* 12: 693–709.
- Rissanen, A.J., P. Ojanen, L. Stenberg, T. Larmola, J. Anttila, S. Tuominen, K. Minkkinen, M. Koskinen, et al. 2023. Vegetation impacts ditch methane emissions from boreal forestry-drained peatlands—Moss-free ditches have an order-of-magnitude higher emissions than moss-covered ditches. *Frontiers in Environmental Science* 11: 1121969.
- Rochefort, L., F. Quilty, S. Campeau, K. Johnson, and T. Malterer. 2003. North American approach to the restoration of Sphagnum dominated peatlands. *Wetlands Ecology and Management* 11: 3–20.
- Rosinski, E., A. Bartel, A. Günther, S. Heinze, B. Hofer, G. Jurasinski, H.-P. Söchting, K. Ullrich, et al. 2021. Restoration of raised bog habitats after grassland use - Three years of vegetation development in the OptiMoor field trial (in German). *Natur Und Landschaft* 96: 192–201.
- Samariks, V., A. Lazdiņš, A. Bārdule, S. Kalēja, A. Butlers, G. Spalva, and Ā. Jansons. 2023. Impact of former peat extraction field afforestation on soil greenhouse gas emissions in Hemiboreal Region. *Forests* 14: 184.
- Santoro, M., O. Cartus, N. Carvalhais, D. Rozendaal, V. Avitabile, A. Araza, S. de Bruin, M. Herold, et al. 2021. The global forest above-ground biomass pool for 2010 estimated from high-resolution satellite observations. *Earth System Science Data* 13: 3927–3950.
- Seddon, N., A. Smith, P. Smith, I. Key, A. Chausson, C. Girardin, J. House, S. Srivastava, et al. 2021. Getting the message right on nature-based solutions to climate change. *Global Change Biology* 27: 1518–1546.
- Siljander, R., M. Cederlöf, and K. Skoglund. 2022. Climate annual report 2022. Helsinki: Ministry of the Environment.
- Simola, H., A. Pitkänen, and J. Turunen. 2012. Carbon loss in drained forestry peatlands in Finland, estimated by re-sampling peatlands surveyed in the 1980s. *European Journal of Soil Science* 63: 798–807.
- Sloan, T.J., R.J. Payne, A.R. Anderson, P. Gilbert, D. Mauquoy, A.J. Newton, and R. Andersen. 2019. Ground surface subsidence in an afforested peatland fifty years after drainage and planting. *Mires and Peat* 23: 6.
- Soimakallio, S., L. Saikku, L. Valsta, and K. Pingoud. 2016. Climate change mitigation challenge for wood utilization—the case of Finland. *Environmental Science & Technology* 50: 5127–5134.

- Soimakallio, S., H. Böttcher, J. Niemi, F. Mosley, S. Turunen, K.J. Hennenberg, J. Reise, and H. Fehrenbach. 2022. Closing an open balance: The impact of increased tree harvest on forest carbon. *Global Change Biology Bioenergy* 14: 989–1000.
- Sokka, L., K. Koponen, and J.T. Keränen. 2015. Cascading use of wood in Finland – with comparison to selected EU countries. Research report VTT-R-03979-15, The Ministry of Employment and the Economy, Finland
- Stachowicz, M., M. Manton, M. Abramchuk, P. Banaszuk, L. Jarašius, A. Kamocki, A. Povilaitis, A. Samerkhanova, et al. 2022. To store or to drain—To lose or to gain? Rewetting drained peatlands as a measure for increasing water storage in the transboundary Neman River Basin. *Science of the Total Environment* 829: 154560.
- Statistics Finland. 2022a. National Inventory Report under the UNFCCC and the Kyoto Protocol. 581 p.
- Statistics Finland. 2022b. Greenhouse gas emissions in 2021 became revised – the land use sector was confirmed a source of emissions. Environment and Nature. Statistics Finland, Helsinki, Finland.
- Tanneberger, F., S. Abel, J. Couwenberg, T. Dahms, G. Gaudig, A. Günther, J. Kreyling, J. Peters, et al. 2021a. Towards net zero CO₂ in 2050: An emission reduction pathway for organic soils in Germany. *Mires and Peat* 27: 5.
- Tanneberger, F., L. Appulo, S. Ewert, S. Lakner, Ó. Brolcháin, and N. Peters J. Wichtmann W. 2021b. The power of nature-based solutions: how peatlands can help us to achieve key EU sustainability objectives. *Advanced Sustainable Systems* 5: 2000146.
- Tunved, P., H.-C. Hansson, V.-M. Kerminen, J. Ström, M. Dal Maso, H. Lihavainen, Y. Viisanen, P.P. Aalto, et al. 2006. High natural aerosol loading over boreal forests. *Science* 312: 261–263.
- UNEP. 2022. Global Peatlands Assessment – The State of the World’s Peatlands: Evidence for action toward the conservation, restoration, and sustainable management of peatlands. Main Report. Global Peatlands Initiative. United Nations Environment Programme, Nairobi.
- Uri, V., M. Kukumägi, J. Aosaar, M. Varik, H. Becker, G. Morozov, and K. Karoles. 2017. Ecosystems carbon budgets of differently aged downy birch stands growing on well-drained peatlands. *Forest Ecology and Management* 399: 82–93.
- Vanguelova, E., S. Chapman, M. Perks, S. Yamulki, T. Randle, F. Ashwood, and J. Morison. 2018. Afforestation and restocking on peaty soils—new evidence assessment. *ClimateXChange*, Scotland
- Walker, X.J., J.L. Baltzer, S.G. Cumming, N.J. Day, C. Ebert, S. Goetz, J.F. Johnstone, S. Potter, et al. 2019. Increasing wildfires threaten historic carbon sink of boreal forest soils. *Nature* 572: 520–523.
- Wilson, D., D. Blain, J. Couwenberg, C.D. Evans, D. Murdiyarmo, S.E. Page, F. Renou-Wilson, J.O. Rieley, et al. 2016. Greenhouse gas emission factors associated with rewetting of organic soils. *Mires and Peat* 17: 04.
- Wilson, D., F. Mackin, J.P. Tuovinen, G. Moser, C. Farrell, and F. Renou-Wilson. 2022. Carbon and climate implications of rewetting a raised bog in Ireland. *Global Change Biology* 28: 6349–6365.
- Yu, Z., J. Loisel, D.P. Brosseau, D.W. Beilman, and S.J. Hunt. 2010. Global peatland dynamics since the Last Glacial Maximum. *Geophysical Research Letters* 37: L13402.
- Zak, D., and R. McInnes. 2022. A call for refining the peatland restoration strategy in Europe. *Journal of Applied Ecology* 59: 2698–2704.
- Zhao, B., Q. Zhuang, N. Shurpali, K. Köster, F. Berninger, and J. Pumpanen. 2021. North American boreal forests are a large carbon source due to wildfires from 1986 to 2016. *Scientific Reports* 11: 7723.
- Zheng, B., P. Ciais, P. Chevallier, H. Yang, J.G. Canadell, Y. Chen, I.R. van der Felde, I. Aben, et al. 2023. Record-high CO₂ emissions from boreal fires in 2021. *Science* 379: 912–917.

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

AUTHOR BIOGRAPHIES

Gerald Jurasinski (✉) holds an engineering degree in Land Management and Environmental Protection from 2000. He obtained his Doctorate from the University of Bayreuth in 2007 in Biogeography. From 2007 until 2022 he worked at the University of Rostock, first as a Postdoc, and from 2014 as Senior Scientist. During 2014–2017 he acted as head of the working group Landscape Ecology. He was visiting scientist at the University of Bergen in 2010 and guest professor at the University of Vienna in 2017 and 2022. Since 2023 he is Professor of Peatland Science at the University of Greifswald. He works broadly on many aspects of peatland research, e.g. on GHG exchange and carbon cycling, rewetting and restoration, and sustainable peatland management. He is editor-in-chief of *Mires & Peat*. *Address:* Institute of Botany and Landscape Ecology, University of Greifswald, Partner in the Greifswald Mire Centre, Greifswald, Germany. *Address:* Laboratory of Flora and Geobotany, Institute of Botany, Nature Research Centre, Vilnius, Lithuania. e-mail: gerald.jurasinski@uni-greifswald.de

Alexandra Barthelmes graduated in Biology and Landscape Ecology from the University of Greifswald in 2000. She then worked at the Department of Botany and Landscape Ecology at the University of Greifswald and for the affiliated non-governmental organisation “DUENE e.V.”. In 2010, she completed her Ph.D. in Landscape Ecology and Nature protection at the University of Greifswald with a thesis on the palaeoecology of forested peatlands in northern Germany. From 2012 onwards, her interest shifted to geographical and geo-spatial work on the location and mapping of peatlands globally, the impact of peatland use on climate change, and towards peatland restoration. She coordinates the Global Peatland Database at the Greifswald Mire Center. *Address:* Institute of Botany and Landscape Ecology, University of Greifswald, Partner in the Greifswald Mire Centre, Greifswald, Germany. e-mail: alex.barthelmes@greifswaldmoor.de

Kenneth A. Byrne graduated in forestry from University College Dublin in 1992. He received his Ph.D. in soil science from University College Dublin in 1999. He joined the University of Limerick in 2008 and is currently a professor in the Department of Biological Sciences and a Principal Investigator at the Bernal Institute. His research focuses on greenhouse gas emissions and carbon stocks in forest and peatland ecosystems. *Address:* Department of Biological Sciences, Faculty of Science and Engineering, University of Limerick, Limerick, Ireland. e-mail: ken.byrne@ul.ie

Bogdan H. Chojnicki graduated in environmental engineering from the Agricultural University of Poznan, Poland, in 1994. Then, he joined the Agrometeorology Department at the Environmental Engineering and Landscape Management Faculty where he received a Ph.D. in heat and water balance of small water bodies (2001). In 2014 he received his habilitation in heat and mass balance micrometeorological techniques. He has been an Associate Professor since 2014 at

the same University. His research activities are focussed on GHG balances of wetland and forest ecosystems.

Address: Laboratory of Bioclimatology, Poznan University of Life Sciences, Poznan, Poland.

e-mail: bogdan.chojnicki@gmail.com

Jesper Riis Christiansen holds a degree in Physical Geography from 2006. He obtained his Ph.D. from University of Copenhagen in 2010 in Soil Biogeochemistry. During 2012–2014 he was a Postdoc at University of British Columbia. From 2014–2017 he was a Postdoc at University of Copenhagen and since 2017 associate professor in the Department of Geoscience and Natural Resource Management. His research focuses on the links between soil hydrology and greenhouse gases in managed and natural ecosystems.

Address: Department of Geoscience and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark.

e-mail: jrc@ign.ku.dk

Kris Decler graduated in 1983 as a biologist from the University of Ghent, Belgium. He is a senior scientist at the Research Institute for Nature and Forest, Brussels (Belgium) where he is active as a landscape ecologist with a main interest for wetland ecosystems and policies for their management and restoration. In 2012 he co-founded the European Chapter of the Society for Ecological Restoration, where he serves as a science-policy interface, especially at the European Commission level.

Address: Research Institute for Nature and Forest, Brussels, Belgium.

e-mail: kris.decler@inbo.be

Christian Fritz graduated in Earth Sciences at the Waikato University Hamilton, New Zealand, in 2006 and earned a Landscape Ecology MSc. degree at Greifswald University in 2007. In 2006, he joined the Centre for Energy and Environmental Studies, University of Groningen, and the Institute of Water and Wetland Research at Radboud University, Nijmegen, the Netherlands. He received his Ph.D. in Life Sciences from Radboud University in 2012 where he continued as Postdoctoral associate and since 2023 as Assistant Professor. Christian and his group quantify greenhouse gas fluxes combined with interactions between water, carbon and nutrients in wet productive peatlands, paludicultures, drained degraded peats soils and mires in restoration.

Address: Department of Aquatic Biology and Environmental Sciences, RIBES, Radboud University Nijmegen, Nijmegen, The Netherlands.

e-mail: christian.fritz@ru.nl

Anke Beate Günther graduated in Biology from the University of Rostock, Germany, in 2010. Also in 2010, she joined the Landscape Ecology group at the same University as a doctorate candidate. She received a doctorate. for her thesis concerning the greenhouse gas exchange of emergent peatland macrophytes in 2015. From 2015 to 2021 she continued to work at the group as a Postdoc in several research projects on peatland restoration and greenhouse gas exchange. Following two years working outside the University, Anke Günther re-joined the Landscape Ecology group at the University of Rostock on a permanent scientist position in 2023. Her research activities focus on peatland restoration, greenhouse gases and vegetation ecology.

Address: Faculty of Agricultural and Environmental Sciences, University of Rostock, Rostock, Germany.

e-mail: anke.guenther@posteo.de

Vytas Huth graduated in agricultural ecology from the University of Rostock, Germany, in 2010 and received a doctorate (Dr. agr.) from the University of Rostock in 2016. He has worked on a variety of projects related to the restoration of temperate peatland ecosystems,

their sustainable use and related climate effects at the Universities of Rostock and Greifswald and the Leibniz Centre for Agricultural Landscape Research (ZALF). Most recently, he is focussing on raised bog restoration for biodiversity and the climate in the nutrient-rich, agricultural environment of north-west Germany.

Address: Faculty of Agricultural and Environmental Sciences, University of Rostock, Rostock, Germany.

e-mail: vytas.huth@uni-rostock.de

Hans Joosten is Professor em. of Peatland Studies and Palaeoecology at Greifswald University, Partner in the Greifswald Mire Centre, and Secretary-General of the International Mire Conservation Group. He is interested in all aspects of peatlands, in all regions of the world and over all times.

Address: Institute of Botany and Landscape Ecology, University of Greifswald, Partner in the Greifswald Mire Centre, Greifswald, Germany.

e-mail: joosten@uni-greifswald.de

Radosław Juszcak graduated in environmental protection from August Cieszkowski Agricultural University in Poznan, Poland, in 2000. He received a Ph.D. in environmental management in 2004 from the same university. From 2004 to 2014, he was an Assistant Professor in the Department of Agrometeorology at the Poznan University of Life Sciences. He was habilitated in 2014. From 2016 to 2019, he was an Associate Professor in the same University. In 2020, he received the title of professor. His current research activities are focussed on the responses of peatland ecosystems to climate manipulation and restoration, including GHG fluxes, plant phenology, vegetation composition and their biophysical and hyperspectral parameters.

Address: Laboratory of Bioclimatology, Poznan University of Life Sciences, Poznan, Poland.

e-mail: radoslaw.juszcak@up.poznan.pl

Sari Juutinen received his Ph.D. degree in biology from University of Eastern Finland in 2004 and she holds the title of docent in ecosystem ecology at the University of Helsinki, Finland. Her research focuses on carbon and greenhouse gas fluxes in lakes and wetlands including terrestrial-aquatic interfaces and interactions.

Address: Faculty of Biological and Environmental Sciences, University of Helsinki, Helsinki, Finland.

e-mail: sari.juutinen@fmi.fi

Åsa Kasimir is a biologist and received a Ph.D. in plant physiology at the Swedish University of Agricultural sciences in 1994. She has since then worked in research and education at different research institutes and universities, and since 2007 at the University of Gothenburg. Here she has been an Associate Professor in physical geography since 2017. Land use and greenhouse gas emissions, from the micro to the landscape scale, has long been the area for her research. The last decade she is focussing on peatland use and greenhouse gas emissions, with outreach to society. She has also been active in the IPCC.

Address: Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden.

e-mail: asa.kasimir@gu.se

Leif Klemetsson started his academic career by a bachelor's degree in biology at Uppsala University 1977, followed by a Ph.D. examen in microbiology at Swedish Agricultural University (SLU, Uppsala) in 1986. He became docent in "Water in the society" 2000 at Linköping Univ, and became professor 2002 at Gothenburg Univ. During his academic carrier he has been working with measuring, modelling and synthesising data on greenhouse gas emissions from terrestrial and aquatic ecosystems. His focus on the terrestrial ecosystems has

been on drained organic soils. He has participated in the IPCC work on emission factors for the “Wetland supplement”

Address: Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden.
e-mail: leif.klemedtsson@gvc.gu.se

Franziska Koebisch graduated in ‘Land Management and Environmental Protection’ from the University of Rostock, Germany, in 2010. In the same year, she joined the Landscape Ecology Group of the University of Rostock as a doctorate candidate and received her doctorate in Agricultural Sciences in 2013. From 2014 to 2024 she hold several Postdoc positions, at the German Research Centre for Geosciences (GFZ), the Swedish University of Agricultural Sciences (SLU), the University of Rostock, and the University of Göttingen with a research focus on ecosystem–climate interactions with a particular scope on peatlands and forests. In her current position at the University of Greifswald, Franziska Koebisch is contributing to develop on better reporting approaches for greenhouse gas emissions from peatlands.

Address: Faculty of Forest Sciences and Forest Ecology, University of Göttingen, Göttingen, Germany.
e-mail: franziska.koebisch@uni-goettingen.de

Wiktoria Kotowski graduated in environmental biology from University of Warsaw, Poland, in 1996. He received a Ph.D. in Natural Sciences from Groningen University, the Netherlands, in 2002 (his thesis was on fen vegetation ecology), and habilitated in ecology from University of Warsaw, in 2014. Wiktoria is now an associate professor at University of Warsaw, doing research on peatland ecology and restoration, with special focus on agriculturally-drained fen systems. He actively engages in conservation and restoration agenda, being a board member of the Wetlands Conservation Centre (PL), International Mire Conservation Group, and several institutional advisory bodies.

Address: Department of Plant Ecology and Environmental Conservation, University of Warsaw, Warsaw, Poland.
e-mail: w.kotowski@uw.edu.pl

Ain Kull graduated in physical geography (physical geography and landscape ecology) and human geography (regional planning) from the University of Tartu, Estonia, in 1995. In 1996, he received an MSc in physical geography. He received a Ph.D. in physical geography and landscape ecology from the University of Tartu in 2001. He works as an Associate Professor in Physical Geography at the Institute of Ecology and Earth Sciences at the University of Tartu. His main research focuses on climate effects on peatland biogeochemistry, human impact on wetlands and peatland restoration, interdisciplinary aspects of natural resources management and spatial planning.

Address: Institute of Ecology and Earth Sciences, University of Tartu, Tartu, Estonia.
e-mail: ain.kull@ut.ee

Mariusz Lamentowicz graduated in geography from the University of Adam Mickiewicz in Poznań, Poland, in 2000. Then, he defended his Ph.D. thesis at the Faculty of Geographical and Geological Sciences in 2004. From 2010 to 2018, after receiving habilitation, he worked as an Associated Professor at the Faculty of Geographical and Geological Sciences, Adam Mickiewicz University, Poland. Since 2018, Mariusz Lamentowicz has worked at the same institution as a Full Professor of Earth Sciences. He leads the climate change ecology research unit. He is focussed on the ecology and long-term ecology of wetlands and forests facing land use and climate changes. He applies experimental and palaeoecological approaches to better

understand present and past global change. His current projects synthesise historical geography and archaeology with palaeoecological perspectives.

Address: Climate Change Ecology Research Unit, Adam Mickiewicz University, Poznań, Poland.
e-mail: mariuszl@amu.edu.pl

Amelie Lindgren graduated in physical geography and ecosystem science from Lund University, Sweden, in 2013. In 2014, she worked as a research assistant at the Department of Physical Geography, Stockholm University, until she begun her Ph.D. studies there in 2016. She received a Ph.D. in Physical Geography from Stockholm University in 2020. After working at the Swedish Environmental Protection Agency from 2020 to 2022, she returned to science as a Postdoc at the Department of Earth Science, Gothenburg University, Sweden, in 2022. She now works as a researcher at the same department since early 2024. Her research activities are focussed on soil carbon storage and land use, with a current emphasis on greenhouse gas dynamics from rewetted organic soils.

Address: Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden.
e-mail: amelie.lindgren@gu.se

Richard Lindsay is Head of Environmental and Conservation Research in the Sustainability Research Institute (SRI), University of East London (UEL). For 20 years he was Senior Peatland Specialist in the UK Nature Conservancy Council and subsequently in Scottish Natural Heritage. During this time he was involved in various high-profile conservation cases, including the battle for the Flow Country in northern Scotland. On leaving SNH in 1996, Richard joined the University of East London. For 16 years he was also Chairman of the International Mire Conservation Group (IMCG).

Address: Sustainability Research Institute, University of East London, London, UK.
e-mail: r.lindsay@uel.ac.uk

Rita Linkevičienė graduated in geography (hydrometeorology) from Vilnius University, Lithuania, in 1993. She studied for a Ph.D. in Physical Sciences (Geography) at the Institute of Geography, Vilnius, since 1996 and defended her thesis in 2002. Since 1993, she works at the Natural Research Centre (formerly the Institute of Geography, Institute of Geology and Geography). From 2013 to 2022, she worked as an assistant professor at the Faculty of Chemistry and Geosciences, Vilnius University. She is currently a senior researcher in the Laboratory for Climate and Water Research at the Natural Research Centre, Vilnius, Lithuania. Her research focuses on raised bog hydrology variation and links with climate and environmental changes.

Address: Laboratory of Climate and Water Research, Nature Research Centre, Vilnius, Lithuania.
e-mail: rita.linkeviciene@gamtc.lt

Annalea Lohila graduated in environmental sciences from the University of Eastern Finland (UEF) in 1998. After working for six years as a Ph.D. candidate at the Finnish Meteorological Institute (FMI), she received her Ph.D. in environmental sciences from UEF in 2008. Until 2018, she worked at FMI as a researcher. From 2019 to 2022, she served as an associate professor at the University of Helsinki and FMI, specialising in biogeochemical cycles. Since 2023, she has held the position of full professor. Her research interests focus on the climate impacts of land use, particularly on peatlands and their management and restoration.

Address: Institute for Atmospheric and Earth System Research, University of Helsinki, Helsinki, Finland.
e-mail: annalea.lohila@fmi.fi

Ülo Mander is Professor of Physical Geography and Landscape Ecology, University of Tartu (UT), Estonia since 1992. He earned his Ph.D. in biology/ecology 1983 at the UT, Estonia. His main research interests are biogeosciences (carbon and nutrient cycling in wetlands and forests), landscape ecology (landscape structure and related material fluxes), and ecological engineering (constructed wetlands and riparian buffers zones). He is an editor/member of the editorial boards of 7 international peer reviewed journals.

Address: Institute of Ecology and Earth Sciences, University of Tartu, Tartu, Estonia.

e-mail: ulo.mander@ut.ee

Michael Manton works with place-based knowledge production and learning towards sustainable landscapes. He is an experienced researcher and professional with a demonstrated history of working in the environmental services industry to balance natural resource production and biodiversity conservation and nature restoration. Michael is a strong research professional with a Ph.D. in Biology, from the Swedish University of Agricultural Sciences.

Address: Bioeconomy Research Institute, Vytautas Magnus University, Akademija, Lithuania.

e-mail: michael.manton@vdu.lt

Kari Minkkinen received his Ph.D. in Peatland Forestry from the University of Helsinki in 1999. Nowadays he works as an Associate Professor in the Department of Forest Sciences, studying and teaching peatland ecology and environmental effects of peatland management.

Address: Department of Forest Sciences, University of Helsinki, Helsinki, Finland.

e-mail: kari.minkkinen@helsinki.fi

Jan Peters landscape ecologist by training, acts as managing director at Michael Succow Foundation, Partner in the Greifswald Mire Centre. His work focuses on peatlands and climate change with main expertise on policy analysis and advocacy, peatland management strategies incl. paludiculture and stakeholder co-creation processes. He holds rich experiences in international projects on climate change mitigation and adaptation, biodiversity conservation and development cooperation connected to peatlands in Europe (e.g. Germany, Baltic States), Asia, Africa, and South America. Additionally, he is chair of the board of Wetlands International European Association.

Address: Michael Succow Foundation, Partner in the Greifswald Mire Centre, Greifswald, Germany.

e-mail: jan.peters@succow-stiftung.de

Florence Renou-Wilson was awarded Ingénieur en Agriculture Degree from ISAB (Institut Supérieur Agricole de Beauvais, France) in 1998 and joined UCD (University College Dublin) where she completed her Masters of Science in Environmental Sciences in UCD (University College Dublin, Ireland) and her Ph.D. degree on “Tree establishment and performance on cutaway peatlands in the Irish midlands” in 2006. Her work primarily aims at investigating peatlands in an integrative way at the crossroads of ecology, forestry, agriculture, climate change and sustainable management.

Address: School of Biology and Environmental Science, University College Dublin, Dublin, Ireland.

e-mail: florence.renou@ucd.ie

Jūratė Sendžikaitė graduated with a degree in Geography and Biology studies (Bachelor’s diploma, 5 years study) at Vilnius Pedagogical University, Lithuania in 1995, and finished Natural Science (Biology) studies (Master’s diploma, 1 year study) in 1996 at the same University. In 1996, she joined the Laboratory of Landscape Ecology at the Institute of Botany (Vilnius, Lithuania). In 2002, she obtained a Ph.D. in Biomedical Sciences (Botany) from the Institute of Botany and Vilnius University (Lithuania). Since 2012, she worked

in different environmental NGOs in Lithuania as peatland restoration expert. Since 2023 she is a lecturer of Natural Sciences at the Faculty of Agrotechnologies of the Vilnius University of Applied Sciences. Her research and practical activities are focussed on restoration, conservation and sustainable usage of peatlands and grasslands.

Address: Foundation for Peatland Restoration and Conservation, Vilnius, Lithuania.

Address: Institute of Geosciences, Faculty of Chemistry and Geosciences, Vilnius University, Vilnius, Lithuania.

e-mail: jurate.sendzikaite@gamtc.lt

Rasa Šimanauskienė has a bachelors degree in Geography (Vilnius university, Lithuania, 1999), Maitrise degree in Geography of University of Sciences and Technologies of Lille (France, 2000) and an M.Sc. in Geography and land management (Vilnius university, Lithuania 2001). She received her Ph.D. in Physical sciences (geography) from Vilnius university in 2005. From 2006 to 2016 she was lecturer in the Department of Geography and Land management at Vilnius university. Since 2016 she has been an Associate professor in the same University. From 2006 to 2019 she also worked as a scientist at the Institute of Geology and Geography. Since 2019 she has been a senior researcher at the Laboratory of Climate and Water Research, Nature Research Centre. Her research activities focus on the application of remote sensing methods to peatland research, ecohydrology, and landscape ecology as well as on interactions between freshwater systems, climate, and human activities.

Address: Laboratory of Climate and Water Research, Nature Research Centre, Vilnius, Lithuania.

Address: Foundation for Peatland Restoration and Conservation, Vilnius, Lithuania.

e-mail: rasa.simanauskiene@gf.vu.lt

Julius Taminskas graduated in geography from Vilnius University, Lithuania, in 1985. In 1985, he joined the Department of Geography at the Institute of Zoology and Parasitology in Vilnius, Lithuania, as a hydrologist. From 1989 to 1993 he joined the laboratory of Lake and Peatland Research, as a Ph.D. candidate. He received his Ph.D. in Natural Sciences from Vilnius University in 1993. From 1994 to 2003, he was senior researcher in the Institute of Geography. From 2003 to 2009, he was senior researcher in the Institute of Geology and Geography. Since 2009, he has been a senior researcher in the Nature Research Centre, Laboratory of Climate and Water Research. His research activities are focussed on wetland research.

Address: Laboratory of Climate and Water Research, Nature Research Centre, Vilnius, Lithuania.

e-mail: julius.taminskas@gamtc.lt

Franziska Tanneberger is a peatland scientist at Greifswald University and Director of the Greifswald Mire Centre, Germany. She works on fen mire ecology and biodiversity, paludiculture, and peatland restoration, particularly within carbon schemes. She has coordinated peatland research and conservation projects in Germany, Russia, Belarus, and Poland. Franziska is editor of the “European Mires Book” (2017) and Coordinating Lead Author for Europe of the Global Peatland Assessment (2022).

Address: Institute of Botany and Landscape Ecology, University of Greifswald, Partner in the Greifswald Mire Centre, Greifswald, Germany.

e-mail: tanne@uni-greifswald.de

Cosima Tegetmeyer studied landscape ecology in Greifswald and completed her Ph.D. in 2015 on the globally endangered aquatic warbler. She has been a research assistant at the Botanical Institute of the University of Greifswald since 2014. Since 2017 her scientific work focuses on the processing of geodata for the Global Peatland Database at the Greifswald Mire Centre.

Address: Institute of Botany and Landscape Ecology, University of Greifswald, Partner in the Greifswald Mire Centre, Greifswald, Germany.
e-mail: tegetmeyec@uni-greifswald.de

Rudy van Diggelen graduated in plant and animal ecology from the University of Groningen, Netherlands, in 1983. After several shorter jobs in nature conservation organisations, he joined the Environmental Institute of Utrecht University as a research assistant in 1986 and the University of Groningen in 1987 at the Laboratory of Plant Ecology, as a Ph.D. candidate and after 1991 as a researcher. He received a Ph.D. in wetland ecology at RU Groningen in 1998. From 1998 to 2008, he was Assistant Professor in the Department of Biology at the same university but changed in 2008 to the University of Antwerp, Belgium. There he was Associate Professor between 2008 and 2010, when he became Full Professor. His research focusses on the functioning of disturbed and restored ecosystems.

Address: Geobiology Research Group, Department of Biology, University of Antwerp, Antwerpen, Belgium.
e-mail: ruurd.vandiggelen@uantwerpen.be

Harri Vasander graduated in plant ecology from the Department of Botany, University of Helsinki, Finland, in 1981. In 1985, he joined the Department of Peatland Forestry of the same university. He received a Ph.D. in mire ecology in 1990. From 2006 to 2022, he was Professor of Peatland Forestry in the Department of Forest Sciences at the University of Helsinki. He retired in 2022. His research activities are focussed on the ecology of pristine, drained and restored peatlands from the subarctic to the tropics.

Address: Department of Forest Sciences, University of Helsinki, Helsinki, Finland.
e-mail: harri.vasander@helsinki.fi

David Wilson graduated from University College Dublin, Ireland in 2001 with a degree in Agricultural Science, specialising in Agricultural and Environmental Science. In 2005, he received his doctorate for his work investigating the impact of peatland restoration on greenhouse gas (GHG) fluxes. Since then, he has been involved in a number of projects researching the impact of land use changes on GHG dynamics. He was a Lead Author in the Inter-Governmental Panel on Climate Change 2013 Wetlands Supplement and is currently a member of the Editorial Board of Mires and Peat.

Address: Earthy Matters, Donegal, Ireland.
e-mail: david.wilson@earthymatters.ie

Nerijus Zableckis Master in ecology, graduated in Vilnius University (Lithuania), since then working in different nature restoration projects (LIFE, Interreg and others) with particular focus on peatlands and

agriculture policy. Since 2012 Nerijus Zableckis is among the establishers of the Foundation for Peatland Restoration and Conservation, which focuses mainly on peatland restoration and paludiculture.

Address: Foundation for Peatland Restoration and Conservation, Vilnius, Lithuania.
e-mail: zableckis@gmail.com

Dominik H. Zak graduated in “Fisheries Science and Aquaculture” at the Humboldt University zu Berlin, Germany, in 2001. In 2004, he joined the “Central Chemical Laboratory” at Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin (IGB Berlin), Germany, as a Ph.D. candidate. He received his Ph.D. in freshwater biology at the Faculty of Mathematics and Natural Sciences, Humboldt University zu Berlin in 2007. From 2008 to 2022, he was first Postdoc and later senior scientist at IGB Berlin, Rostock University and Aarhus University. Since 2023, he has been a Professor of Freshwater Ecology in the Department of Ecoscience at Aarhus University. His research activities focus on biogeochemical processes, matter fluxes, and nutrient dynamics within various wetland systems, with a particular focus on the cycles of phosphorus, nitrogen, carbon, sulphur, and iron.

Address: Institute of Ecoscience, Aarhus University, Aarhus, Denmark.

Address: Leibniz-Institute of Freshwater Ecology and Inland Fisheries Berlin, Berlin, Germany.
e-mail: doz@ecos.au.dk

John Couwenberg graduated in bioinformatics and palaeoecology from the University of Utrecht, Netherlands, in 1997. He then helped set up the working group for Peatland Studies and Palaeoecology at the University of Greifswald, Germany. He acted as a Lead Author for two 2013 IPCC guidelines. He received his Ph.D. from the University of Greifswald in 2021. From 2021 until 2022, he was interim leader of the working group and then became senior scientist at the group for Peatland Sciences at the University of Greifswald in 2023. His research activities are focussed on palaeoecology, self-organisation, landscape ecology, ecohydrology, matter dynamics, greenhouse gas emissions and reporting, carbon crediting and paludiculture.

Address: Institute of Botany and Landscape Ecology, University of Greifswald, Partner in the Greifswald Mire Centre, Greifswald, Germany.
e-mail: couwenberj@uni-greifswald.de