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Topsoil removal and *Sphagnum* spreading improve the climate balance of peat bog restoration

Gerald Jurasinski[1], Vytas Huth[1], Eva Rosinski[2], Cordula Gutekunst[1], Franziska Koebsch[1], Bernd Hofer[2], Stefanie Heinze[3], Karin Ullrich[3], and Anke Günther[1]

[1]University of Rostock, Faculty of Agricultural and Environmental Sciences, Landscape Ecology, Rostock, Germany (gerald.jurasinski@uni-rostock.de)

[2]Hofer & Pautz GbR, Altenberge, Germany

[3]Bundesamt für Naturschutz, Bonn, Germany

Many peatlands in Central Europe are under unsustainable drainage-based land use with high greenhouse gas emissions counteracting the aims of the Paris Agreement. After decades of drained and intensive land use many peat bogs are in pitiful state. Rewetting can stop the carbon dioxide (CO_2) source function but may result in high methane (CH_4) emissions and eutrophication. Further, lack of diaspores my hamper the establishment of typical bog species. Restoration measures like topsoil removal (TSR) or spreading target vegetation propagules are known to improve restoration success in fen peatlands or after peat extraction. However, experience on restoration of bogs after previous agricultural use is scarce and the climate effects of these restoration measures including carbon losses from TSR are unknown.

We installed a field trial in a drained bog in North-West Germany to explore the effect of TSR and Sphagnum spreading on greenhouse (GHG) emissions. The trial consists of seven plots (~8 x 24 m each) representing the status quo—intensive grassland use—and six different restoration approaches. Two approaches are rewetting on the original surface with or without regular biomass harvesting. The remaining four represent TSR prior rewetting where two of the four were inoculated with *Sphagnum* spp. On all plots we measured GHG fluxes fortnightly using closed chambers to obtain two-year GHG budgets. We assessed the climate effects of the status quo and the six restoration approaches by applying a radiative forcing model to the GHG budgets and to published emission factors while incorporating the effect of TSR through different depletion scenarios of the exported topsoil carbon.

Compared to the status quo, rewetting alone reduced CO_2 emissions by ~75% but substantially increased CH_4 emissions, which were much higher than published emission factors for a similar peatland category. After TSR, on-site CO_2 emissions were close to 0 or—with Sphagnum spreading—net negative while CH_4 emissions remained very low. Based on our GHG budgets, TSR quickly becomes less climate warming than keeping the status quo and rewetting at the original surface. In contrast, based on emission factors, rewetting at the original surface is initially the least climate warming option.

In general, the climatic effect of TSR is likely lowest when removing only as much topsoil as necessary to implement nutrient-poor and acidic conditions thereby ensuring rapid establishment of a *Sphagnum* carpet and by conserving the removed topsoil as long as possible. Here, the climate warming effect of TSR of ~30 cm in combination with rewetting roughly corresponds to the climate warming of rewetted nutrient-rich temperate peatlands without TSR. Therefore, from a climate perspective, we can recommend a shallow TSR of up to 30 cm for peat bog restoration given that the goal is to re-establish typical bog habitats.