Greenhouse gas emissions from restored agricultural wetlands – a review

Nielsen & Kjærgaard. In prep.

Abstract

Over the past 100 years, many temperate wetlands have been drained for agricultural purposes. These ecosystems are in their natural state characterized by high amounts of organic carbon (C) in the soil due to a slow build-up over thousands of years. But when drained, the organic C is rapidly respired as carbon dioxide (CO_2) by decomposing microorganisms, and thus these drained wetlands release large amounts of this potent greenhouse gas to the atmosphere. There is therefore a growing interest to restore these wetlands in order to prevent further loss of carbon and release of (CO_2), but the effects of wetland restoration on greenhouse gas emissions are uncertain due to a scarcity of studies and syntheses. This review therefore aims to provide an overview of current knowledge within the field, identify knowledge gaps, and give directions for future studies.

Drained and restored temperate wetlands can be both greenhouse gas sinks and sources and the emissions are in the range of -800 to 675 g CO_2eq m^{-2} y^{-1} and most of the available studies show that the restored temperate wetlands generally have a small emission or a small to large uptake of greenhouse gasses (mainly as CO_2). In contrast, restored wetlands in warmer climate zones show a tendency to larger emissions with the range of -395 – 3500 g CO_2eq m^{-2} y^{-1}. In case of large emissions, these are driven by large fluxes of methane (CH_4).

There is not a consensus in literature about the effect of time after restoration on greenhouse gas budgets from restored wetlands. Some studies show high initial emissions and a gradual transition towards lower emissions or a net uptake, while other studies show sustained high emissions over longer time periods. There is therefore a need for more research on this topic to tease out the different effects of time, previous land use, climate conditions and ecosystem type.

References

Anderson, F.E., Bergamaschi, B., Sturtevant, C., Knox, S., Hastings, L., Windham-Myers, L., Detto, M., Hestir, E.L., Drexler, J., Miller, R.L., 2016. Variation of energy and carbon fluxes from a restored temperate freshwater wetland and implications for carbon market verification protocols. Journal of Geophysical Research: Biogeosciences 121, 777–795.

Audet, J., Elsgaard, L., Kjaergaard, C., Larsen, S.E., Hoffmann, C.C., 2013. Greenhouse gas emissions from a Danish riparian wetland before and after restoration. Ecological Engineering 57, 170–182. doi:10.1016/J.ECOLENG.2013.04.021

Audet, J., Hoffmann, C.C., Andersen, P.M., Baattrup-Pedersen, A., Johansen, J.R., Larsen, S.E., Kjaergaard, C., Elsgaard, L., 2014. Nitrous oxide fluxes in undisturbed riparian wetlands located in agricultural catchments: Emission, uptake and controlling factors. Soil Biology and Biochemistry 68, 291–299. doi:10.1016/J.SOILBIO.2013.10.011

Beetz, S., Liebersbach, H., Glatzel, S., Jurasinski, G., Buczko, U., Höper, H., 2013. Effects of land use intensity on the full greenhouse gas balance in an Atlantic peat bog. Biogeosciences 10, 1067–1082. doi:10.5194/bg-10-1067-2013

Bortolotti, L.E., st. Louis, V.L., Vinebrooke, R.D., Wolfe, A.P., 2016. Net Ecosystem Production and Carbon Greenhouse Gas Fluxes in Three Prairie Wetlands. Ecosystems 19, 411–425. doi:10.1007/s10021-015-9942-1

Chamberlain, S.D., Anthony, T.L., Silver, W.L., Eichelmann, E., Hemes, K.S., Oikawa, P.Y., Sturtevant, C., Szutu, D.J., Verfaillie, J.G., Baldocchi, D.D., 2018. Soil properties and sediment accretion modulate methane fluxes from restored wetlands. Global Change Biology 24, 4107–4121. doi:10.1111/gcb.14124

Groh, T.A., Gentry, L.E., David, M.B., 2015. Nitrogen Removal and Greenhouse Gas Emissions from Constructed Wetlands Receiving Tile Drainage Water. Journal of Environmental Quality 44, 1001–1010. doi:10.2134/jeq2014.10.0415

Hemes, K.S., Chamberlain, S.D., Eichelmann, E., Anthony, T., Valach, A., Kasak, K., Szutu, D., Verfaillie, J., Silver, W.L., Baldocchi, D.D., 2019. Assessing the carbon and climate benefit of restoring degraded agricultural peat soils to managed wetlands. Agricultural and Forest Meteorology 268, 202–214. doi:10.1016/J.AGRFORMET.2019.01.017

Hemes, K.S., Chamberlain, S.D., Eichelmann, E., Knox, S.H., Baldocchi, D.D., 2018. A Biogeochemical Compromise: The High Methane Cost of Sequestering Carbon in Restored Wetlands. Geophysical Research Letters 45, 6081–6091. doi:10.1029/2018GL077747

Hendriks, D.M.D., van Huissteden, J., Dolman, A.J., van der Molen, M.K., 2007. The full greenhouse gas balance of an abandoned peat meadow. Biogeosciences 4, 411–424. doi:10.5194/bg-4-411-2007

Henneberg, A., Sorrell, B.K., Brix, H., 2012. Internal methane transport through Juncus effusus: experimental manipulation of morphological barriers to test above- and below-ground diffusion limitation. New Phytol 196, 799–806. doi:10.1111/j.1469-8137.2012.04303.x

Herbst, M., Friborg, T., Ringgaard, R., Soegaard, H., 2011. Interpreting the variations in atmospheric methane fluxes observed above a restored wetland. Agricultural and Forest Meteorology 151, 841–853. doi:10.1016/j.agrformet.2011.02.002

Herbst, M., Friborg, T., Schelde, K., Jensen, R., Ringgaard, R., Vasquez, V., Thomsen, A.G., Soegaard, H., 2013. Climate and site management as driving factors for the atmospheric greenhouse gas exchange of a restored wetland. BIOGEOSCIENCES 10, 39–52. doi:10.5194/bg-10-39-2013

Joosten, H., 2009. The Global Peatland CO2 Picture: peatland status and drainage related emissions in all countries of the world. The Global Peatland CO2 Picture: Peatland Status and Drainage Related Emissions in All Countries of the World.

Kandel, T., Lærke, P., Hoffmann, C., Elsgaard, L., 2018. Complete annual CO 2 , CH 4 , and N 2 O balance of a temperate riparian wetland 12 years after rewetting. Ecological Engineering. doi:10.1016/j.ecoleng.2017.12.019

Knox, S.H., Sturtevant, C., Matthes, J.H., Koteen, L., Verfaillie, J., Baldocchi, D., 2015. Agricultural peatland restoration: effects of land-use change on greenhouse gas (CO2 and CH4) fluxes in the Sacramento-San Joaquin Delta. Global Change Biology 21, 750–765. doi:10.1111/gcb.12745

Lai, D.Y.F., 2009. Methane Dynamics in Northern Peatlands: A Review. Pedosphere 19, 409–421. doi:10.1016/s1002-0160(09)00003-4

Laine, A.M., Mehtätalo, L., Tolvanen, A., Frolking, S., Tuittila, E.-S., 2019. Impacts of drainage, restoration and warming on boreal wetland greenhouse gas fluxes. Science of The Total Environment 647, 169–181. doi:10.1016/J.SCITOTENV.2018.07.390

Leifeld, J., Menichetti, L., 2018. The underappreciated potential of peatlands in global climate change mitigation strategies. Nature Communications 9, 1071. doi:10.1038/s41467-018-03406-6

le Mer, J., Roger, P., 2001. Production, oxidation, emission and consumption of methane by soils: A review. European Journal of Soil Biology 37, 25–50. doi:10.1016/s1164-5563(01)01067-6

McNicol, G., Sturtevant, C., Knox, S., Dronova, I., Baldocchi, D., Silver, W., 2016. Effects of seasonality, transport-pathway, and spatial structure on greenhouse gas fluxes in a restored wetland. Global Change Biology 23. doi:10.1111/gcb.13580

McNicol, G., Sturtevant, C.S., Knox, S.H., Dronova, I., Baldocchi, D.D., Silver, W.L., 2017. Effects of seasonality, transport pathway, and spatial structure on greenhouse gas fluxes in a restored wetland. Global Change Biology 23, 2768–2782. doi:10.1111/gcb.13580

Morse, J.L., Ardón, M., Bernhardt, E.S., 2012. Greenhouse gas fluxes in southeastern U.S. coastal plain wetlands under contrasting land uses. Ecological Applications 22, 264–280. doi:10.1890/11-0527.1

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., Zhang, H., 2013. Anthropogenic and Natural Radiative Forcing, in: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 659–740. doi:10.1017/CBO9781107415324.018

Scharlemann, J.P.W., Tanner, E.V.J., Hiederer, R., Kapos, V., 2014. Global soil carbon: understanding and managing the largest terrestrial carbon pool. Carbon Management 5, 81–91. doi:10.4155/cmt.13.77

Schrier-Uijl, A.P., Kroon, P.S., Hendriks, D.M.D., Hensen, A., van Huissteden, J., Berendse, F., Veenendaal, E.M., 2014. Agricultural peatlands: Towards a greenhouse gas sink - A synthesis of a Dutch landscape study. Biogeosciences 11, 4559–4576. doi:10.5194/bg-11-4559-2014

Segers, R., 1998. Methane production and methane consumption: a review of processes underlying wetland methane fluxes. Biogeochemistry 41, 23–51. doi:10.1023/a:1005929032764

Sha, C., Mitsch, W.J., Mander, Ü., Lu, J., Batson, J., Zhang, L., He, W., 2011. Methane emissions from freshwater riverine wetlands. Ecological Engineering 37, 16–24. doi:https://doi.org/10.1016/j.ecoleng.2010.07.022

Tangen, B.A., Finocchiaro, R.G., Gleason, R.A., 2015. Effects of land use on greenhouse gas fluxes and soil properties of wetland catchments in the Prairie Pothole Region of North America. Science of The Total Environment 533, 391–409. doi:10.1016/J.SCITOTENV.2015.06.148

Vidon, P., Jacinthe, P.-A., Liu, X., Fisher, K., Baker, M., 2014. Hydrobiogeochemical Controls on Riparian Nutrient and Greenhouse Gas Dynamics: 10 Years Post-Restoration. JAWRA Journal of the American Water Resources Association 50, 639–652. doi:10.1111/jawr.12201

Whalen, S.C., 2005. Biogeochemistry of methane exchange between natural wetlands and the atmosphere. Environmental Engineering Science 22, 73–94. doi:10.1089/ees.2005.22.73

Whitman, W.B., Bowen, T.L., Boone, D.R., 2006. The Methanogenic Bacteria, in: Dworkin M., F.S. (Ed.), The Procaryotes. pp. 165–207.

Wrage, N., Velthof, G.L., van Beusichem, M.L., Oenema, O., 2001. Role of nitrifier denitrification in the production of nitrous oxide. Soil Biology and Biochemistry 33, 1723–1732. doi:10.1016/S0038-0717(01)00096-7

Zedler, J.B., Kercher, S., 2005. WETLAND RESOURCES: Status, Trends, Ecosystem Services, and Restorability. Annual Review of Environment and Resources 30, 39–74. doi:10.1146/annurev.energy.30.050504.144248