Small Ponds and carbon capture

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The UK Government Department for Energy Security and Net Zero update on Climate Change in June 2023 (UK Government, 2024) includes a series of stark and direct statements regarding climate change, highlighting the need to capture carbon and remove it from the atmosphere. Natural ponds, and other small freshwater bodies in the UK can increase the capture of organic carbon. Lakes (Kastowski *et al.*, 2011, Mendonça 2017, Anderson *et al.*, 2013) and rivers (Ho *et al.*, 2020) have been known to have a role in carbon capture but only recently has the role of small ponds been considered. Small ponds (generally with a maximum depth of 5 m and surface area of < 5 ha) have a carbon capture role (Downing *et al.*, 2008, Holgerson, 2024, Cere´ghino *et al.*, 2014). Gilbert *et al.* (2014) studied ponds of less than 400 m^2, and found carbon density was highest in sediments of permanent ponds and in ponds with a diverse wetland flora. Permanent, naturally vegetated ponds accumulated the highest percentage of organic carbon and were least affected by climatic variation (Gilbert *et al.*, 2014). Taylor *et al.* (2019) worked on 'micro-ponds' of 1m^2 and identified that there was period over the first 3 years of a 1m^2 pond's life when carbon capture was negligible but the subsequent rate over 20 years established the ponds as carbon 'sinks'. Taylor *et al.* (2019) found organic carbon burial rates varied depending on the pond's vegetation. Downing *et al.* (2008) studied a range of waterbodies of different sizes and found the level of burial of organic carbon increased as size decreased.

Jefferies *et al.* (2023) gathered information relating to organic carbon in pond sediments and estimated a measure which could be extrapolated to a figure for the UK of approximately 2.625 million metric tonnes of organic carbon 'stored' in ponds. This burial rate is 20 to 30 times higher than woodlands and grasslands and higher than those of other natural wetlands. However, ponds have the potential to act both as carbon 'sinks' *and* 'sources', with CO_2, CH_4 and N_2O greenhouse gas emissions taking place (Audet *et al.*, 2020, Cambronero *et al.*, 2022, Herrero Ortega, 2019, Holgerson and Raymond, 2016, Rosentreter *et al.*, 2021, Davidson at al, 2018, Ljung and Lin, 2023 and Peacock, 2021). Soued *et al.* (2016) suggested that N_2O pond emissions were negligible when compared to those from lakes and rivers, an argument supported by studies by Mander *et al.* (2014), Sovik *et al.* (2006) and Webb (2019). Taylor *et al.*'s (2019) results suggested methane fluxes measured in ponds in the UK were equivalent to only 1.7% of the organic carbon burial rate and, although CO_2 flux rates in ponds can switch

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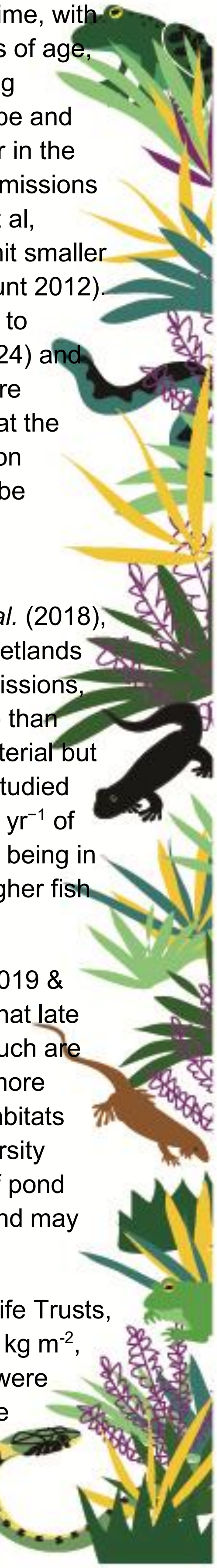
rapidly from 'sink' to 'source' as they dry (Gilbert *et al.* 2017), over their successional cycle small ponds act as carbon 'sinks'. Taylor *et al.* (2019) found carbon burial rates varied over time, with young ponds sequestering carbon at a lower rate than mature ponds. At 19 to 25 years of age, sediment burial rates decrease but ponds still provide an ecosystem service by trapping sediments and elements (Rogers *et al.*, 2022). Rogers *et al.* (2022) found that pond type and substrate type have an influence on carbon sequestration; as ponds become shallower in the latter stages of the succession, the exposure of sediment increases greenhouse gas emissions but, as they dry, ponds gain vegetation that mitigates methane emissions (Davidson at al, 2018). Ponds with denser vegetation cover and emergent vegetation were found to emit smaller amounts of CO_2 as they dried and capture more carbon (Gilbert *et al.* 2021, More & Hunt 2012). Vegetation type and quantity and stratification during the summer months are believed to influence the release of CO_2 and CH_4 over time (Rabaey & Cotner, 2024; Sǿ *et al.* (2024) and littoral zones and shelves that enable vegetation growth and increase carbon uptake are important in pond design (Merriman *et al.*, 2017). Taylor *et al.*'s (2019) results show that the diversity of pond communities is important when characterising differences in the carbon capture function of different ponds. Gilbert *et al.* (2021) argued high carbon burial can be attributed to high nutrient concentrations driving primary productivity, high levels of soil particulate transfer from adjacent land, and continuous sediment anoxia.

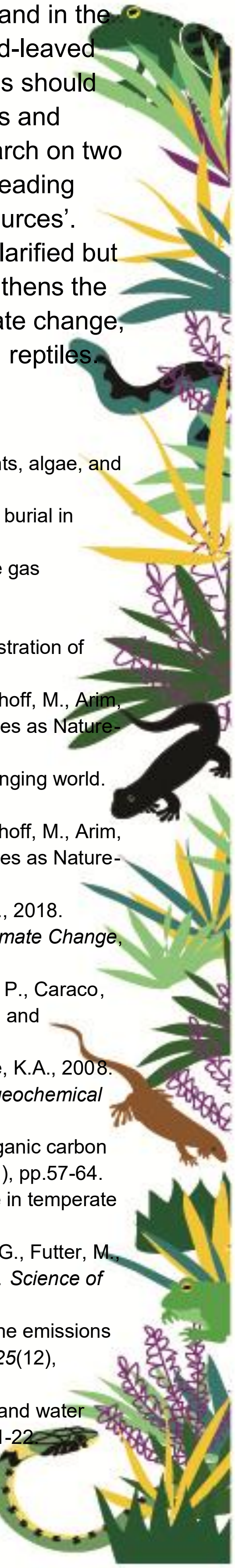
Other ponds such as beaver ponds are now also found to operate as 'sinks', (Gatti *et al.* (2018), Puttock *et al.* (2018) and Mitsch *et al.* (2013) studied carbon fluxes from constructed wetlands and argued that when balanced over time, carbon sequestration exceeds methane emissions, and they can also be net 'sinks'. Aquaculture ponds bury carbon at a lesser rate (70%) than large water bodies and agricultural water bodies because of a low input of external material but still act as 'sinks' (Boyd *et al.*, 2010, Annikuttan *et al.*, 2016). Holgerson *et al.* (2024) studied ponds of $900m^2$ area, and found that over 57 years these ponds sequestered $67\ g\ m^{-2}\ yr^{-1}$ of autochonthous organic carbon, twice that of their estimates for lakes; the highest rates being in ponds with higher numbers of submerged macrophytes and the lower in ponds with higher fish introductions (Holgerson *et al.*, 2024).

Small ponds have a significant role in the conservation of biodiversity (Lewis-Phillips 2019 & 2020) and flood management (Cambronero *et al.*, 2022). Taylor *et al.* (2019) argued that late succession, drying or newly dry ponds are often considered as species-poor, and as such are often targeted for restoration to enhance biodiversity. Taylor *et al.* (2019) proposed a more effective strategy; to build new ponds near to existing pond sites, retaining the older habitats and creating pond clusters, part of a 'pondscape', which would support greater biodiversity (Williams *et al.*, 2010) and increase the potential for carbon burial. The construction of pond networks or 'pondscapes' are significant for amphibians which move between ponds and may breed successfully in different ponds in different environmental conditions.

If we consider 500,000 ponds lost from the UK 'pondscape' in the last 100 years (Wildlife Trusts, 2024), and use the value of carbon storage estimated by Jefferies *et al.* (2023) of $9.38\ kg\ m^{-2}$, we can estimate that 2.73 million tonnes additional carbon per year could be retained were those 500,000 lost ponds to be replaced. Admittedly many lost ponds will have become vegetated and be continuing to store carbon, but this figure supports the case for pond



restoration and the creation of ‘pond clusters’ within a national ‘pondscape’. Taylor *et al.* (2019) estimated that small ponds take up less than 100th of the area of broad-leaved woodland in the UK but contribute the equivalent of 1/3 of the carbon capture of the total area of broad-leaved woodland. Ray and Holgerson (2023) and (Ray *et al.* 2023) argue strongly that ponds should not be considered in a ‘global’ context because of the wide variation in measurements and estimates used as proxies for actual measures of $C0_2$ and CH_4 release. Recent research on two ponds in the USA found that carbon emissions were similar to carbon sequestration leading Holgerson *et al.* (2026) to suggest that some ponds may act as ‘sinks’ rather than ‘sources’. The reasons why some ponds have different roles in carbon budgets remains to be clarified but the value of ponds as carbon sinks (Mitsch *et al.*, 2013, Hamback *et al.*,2023), strengthens the arguments for pond creation as a practical and beneficial strategy for managing climate change, resolving water storage issues improving biodiversity and supporting amphibians and reptiles.



References

Anikuttan, K.K., Adhikari, S., Kavitha, M. and Jayasankar, P., 2016. Carbon sequestration capacity of sediments, algae, and zooplankton from freshwater aquaculture ponds. *Environmental monitoring and assessment*, *188*, pp.1-5.

Anderson, N.J., Dietz, R.D. and Engstrom, D.R., 2013. Land-use change, not climate, controls organic carbon burial in lakes. *Proceedings of the Royal Society B: Biological Sciences*, *280*(1769), p.20131278.

Audet, J., Carstensen, M. V., Hoffmann, C. C., Lavaux, L., Thiemer, K., & Davidson, T. A. (2020). Greenhouse gas emissions from urban ponds in Denmark. Inland Waters, 10(3), 373–385. https://doi.org/10.1080/20442041.2020.1730680

Boyd, C.E., Wood, C.W., Chaney, P.L. and Queiroz, J.F., 2010. Role of aquaculture pond sediments in sequestration of annual global carbon emissions. *Environmental pollution*, *158*(8), pp.2537-2540.

Cuenca-Cambronero, M., Blicharska, M., Perrin, J.A., Davidson, T.A., Oertli, B., Lago, M., Beklioglu, M., Meerhoff, M., Arim, M., Teixeira, J. and De Meester, L., 2023. Challenges and opportunities in the use of ponds and pondscapes as Nature-based Solutions. *Hydrobiologia*, *850*(15), pp.3257-3271.

Céréghino, R., Boix, D., Cauchie, H.M., Martens, K. and Oertli, B., 2014. The ecological role of ponds in a changing world. *Hydrobiologia*, *723*, pp.1-6.

Cuenca-Cambronero, M., Blicharska, M., Perrin, J.A., Davidson, T.A., Oertli, B., Lago, M., Beklioglu, M., Meerhoff, M., Arim, M., Teixeira, J. and De Meester, L., 2023. Challenges and opportunities in the use of ponds and pondscapes as Nature-based Solutions. *Hydrobiologia*, *850*(15), pp.3257-3271.

Davidson, T.A., Audet, J., Jeppesen, E., Landkildehus, F., Lauridsen, T.L., Søndergaard, M. and Syväranta, J., 2018. Synergy between nutrients and warming enhances methane ebullition from experimental lakes. *Nature Climate Change*, *8*(2), pp.156-160.

Downing, J.A., Prairie, Y.T., Cole, J.J., Duarte, C.M., Tranvik, L.J., Striegl, R.G., McDowell, W.H., Kortelainen, P., Caraco, N.F., Melack, J.M. and Middelburg, J.J., 2006. The global abundance and size distribution of lakes, ponds, and impoundments. *Limnology and oceanography*, *51*(5), pp.2388-2397.

Downing, J.A., Cole, J.J., Middelburg, J.J., Striegl, R.G., Duarte, C.M., Kortelainen, P., Prairie, Y.T. and Laube, K.A., 2008. Sediment organic carbon burial in agriculturally eutrophic impoundments over the last century. *Global biogeochemical cycles*, *22*(1).

Gilbert, P.J., Taylor, S., Cooke, D.A., Deary, M., Cooke, M. and Jeffries, M.J., 2014. Variations in sediment organic carbon among different types of small natural ponds along Druridge Bay, Northumberland, UK. *Inland Waters*, *4*(1), pp.57-64.

Gilbert, P.J., Taylor, S., Cooke, D.A., Deary, M.E. and Jeffries, M.J., 2021. Quantifying organic carbon storage in temperate pond sediments. *Journal of Environmental Management*, *280*, p.111698.

Hambäck, P.A., Dawson, L., Geranmayeh, P., Jarsjö, J., Kačergytė, I., Peacock, M., Collentine, D., Destouni, G., Futter, M., Hugelius, G. and Hedman, S., 2023. Tradeoffs and synergies in wetland multifunctionality: A scaling issue. *Science of the Total Environment*, *862*, p.160746.

Herrero Ortega, S., Romero González-Quijano, C., Casper, P., Singer, G.A. and Gessner, M.O., 2019. Methane emissions from contrasting urban freshwaters: Rates, drivers, and a whole-city footprint. *Global change biology*, *25*(12), pp.4234-4243.

Ho, L., Jerves-Cobo, R., Barthel, M., Six, J., Bode, S., Boeckx, P. and Goethals, P., 2020. Effects of land use and water quality on greenhouse gas emissions from an urban river system. *Biogeosciences Discussions*, *2020*, pp.1-22.

Holgerson, M.A., Ray, N.E., Gannon, K.A. and Heathcote, A.J., 2026. Carbon fluxes in two temperate ponds are mediated by stratification and primary producers. *Limnology and Oceanography*, *71*(1), p.e70273.

Holgerson, M.A., Ray, N.E. and Russ, C., 2024. High rates of carbon burial linked to autochthonous production in artificial ponds. *Limnology and Oceanography Letters*, *9*(1), pp.43-51.

Holgerson, M.A. and Raymond, P.A., 2016. Large contribution to inland water CO2 and CH4 emissions from very small ponds. *Nature Geoscience*, *9*(3), pp.222-226.

Jeffries, M.J., Gilbert, P.J., Taylor, S., Cooke, D.A. and Deary, M.E., 2023. Organic carbon in British lowland ponds: estimating sediment stocks, possible practical benefits and significant unknowns. *Hydrobiologia*, *850*(15), pp.3225-3239.

Kastowski, M., Hinderer, M. and Vecsei, A., 2011. Long‐term carbon burial in European lakes: Analysis and estimate. *Global Biogeochemical Cycles*, *25*(3).

Lewis-Phillips, J., Brooks, S.J., Brooks, S.J., Sayer, C.D., McCrea, R.S., Siriwardena, G.M., & Axmacher, J.C. (2019). Pond management enhances the local abundance and species richness of farmland bird communities. Agriculture, Ecosystems & Environment. 273 pp. 130-140

Lewis-Phillips, J., Brooks, S.J., Sayer, C.D., Patmore, I.R., Hilton, G.M., Harrison, A.L., Robson, H.J., & Axmacher, J.C. (2020). Ponds as insect chimneys: Restoring overgrown farmland ponds benefits birds through elevated productivity of emerging aquatic insects. Biological Conservation, 241, 108253.

Mander, Ü., Dotro, G., Ebie, Y., Towprayoon, S., Vhiemchaisri, C., Nogueira, S.F., Jamsranjav, B., Kasak, K., Truu, J., Tournebize, J., Mitsch, W.J., 2014. Greenhouse gas emission in constructed wetlands for wastewater treatment: a review. Ecol. Eng. 66, 19–35. https://doi.org/10.1016/j.ecoleng.2013.12.006.

Mendonça, R., Müller, R.A., Clow, D., Verpoorter, C., Raymond, P., Tranvik, L.J. and Sobek, S., 2017. Organic carbon burial in global lakes and reservoirs. *Nature communications*, *8*(1), p.1694.

Merriman, L.S., Moore, T.L.C., Wang, J.W., Osmond, D.L., Al-Rubaei, A.M., Smolek, A.P., Blecken, G.T., Viklander, M. and Hunt, W.F., 2017. Evaluation of factors affecting soil carbon sequestration services of stormwater wet retention ponds in varying climate zones. *Science of the total environment*, *583*, pp.133-141.

Mitsch, W.J., Bernal, B., Nahlik, A.M., Mander, Ü., Zhang, L., Anderson, C.J., Jørgensen, S.E. and Brix, H., 2013. Wetlands, carbon, and climate change. *Landscape ecology*, *28*, pp.583-597.

Moore, T.L. and Hunt, W.F., 2012. Ecosystem service provision by stormwater wetlands and ponds–a means for evaluation?. *Water research*, *46*(20), pp.6811-6823.

Peacock, M., Audet, J., Bastviken, D., Cook, S., Evans, C.D., Grinham, A., Holgerson, M.A., Högbom, L., Pickard, A.E., Zieliński, P. and Futter, M.N., 2021. Small artificial waterbodies are widespread and persistent emitters of methane and carbon dioxide. *Global Change Biology*, *27*(20), pp.5109-5123.

Puttock, A., Graham, H.A., Carless, D. and Brazier, R.E., 2018. Sediment and nutrient storage in a beaver engineered wetland. *Earth Surface Processes and Landforms*, *43*(11), pp.2358-2370.

Rabaey, J.S. and Cotner, J.B., 2024. The influence of mixing on seasonal carbon dioxide and methane fluxes in ponds. *Biogeochemistry*, *167*(10), pp.1297-1314.

Rogers, M.N., Williamson, T.J., Knoll, L.B. and Vanni, M.J., 2022. Temporal patterns in sediment, carbon, and nutrient burial in ponds associated with changing agricultural tillage. *Biogeochemistry*, *159*(1), pp.87-102.

Rosentreter, J.A., Borges, A.V., Deemer, B.R., Holgerson, M.A., Liu, S., Song, C., Melack, J., Raymond, P.A., Duarte, C.M., Allen, G.H. and Olefeldt, D., 2021. Half of global methane emissions come from highly variable aquatic ecosystem sources. *Nature Geoscience*, *14*(4), pp.225-230.

Soued, C., Del Giorgio, P.A. and Maranger, R., 2016. Nitrous oxide sinks and emissions in boreal aquatic networks in Québec. *Nature Geoscience*, *9*(2), pp.116-120.

Sø, J.S., Martinsen, K.T., Kragh, T. and Sand-Jensen, K., 2024. Hourly methane and carbon dioxide fluxes from temperate ponds. *Biogeochemistry*, *167*(2), pp.177-195.

So vik, A.K., Augustin, J., Heikkinen, K., Huttunen, J.T., Necki, J.M., Karjalainen, S.M., Kl⊘ ve, B., Liikanen, A., Mander, Ü., Puustinen, M. and Teiter, S., 2006. Emission of the greenhouse gases nitrous oxide and methane from constructed wetlands in Europe. *Journal of environmental quality*, *35*(6), pp.2360-2373.

Taylor, S., Gilbert, P.J., Cooke, D.A., Deary, M.E. and Jeffries, M.J., 2019. High carbon burial rates by small ponds in the landscape. *Frontiers in Ecology and the Environment*, *17*(1), pp.25-31.

UK Government, (2024a. Climate change explained - GOV.UK (www.gov.uk) [online: accessed May 2024]

Webb, J.R., Hayes, N.M., Simpson, G.L., Leavitt, P.R., Baulch, H.M. and Finlay, K., 2019. Widespread nitrous oxide undersaturation in farm waterbodies creates an unexpected greenhouse gas sink. *Proceedings of the National Academy of Sciences*, *116*(20), pp.9814-9819.

Williams P, Whitfield M, Biggs J. How can we make new ponds biodiverse? A case study monitored over 7 years. Pond Conservation in Europe. 2010:137-48.

Wildlife Trusts, 2024. Ponds https://www.wildlifetrusts.org/habitats/freshwater/ponds [online: accessed May 2024]