A Review of the Role of Agricultural Ponds in England

Climate change and biodiversity risks and opportunities

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Natural England Commissioned Report NECR490

Supplement 1 – Paper Summary

NATURAL ENGLAND

Natural England Agricultural Ponds

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Paper 4.

Biggs, J., von Fumetti, S. and Kelly-Quinn, M. (2017) 'The importance of small waterbodies for biodiversity and ecosystem services: implications for policy makers', Hydrobiologia, 793(1), pp. 3–39. Available at: https://doi.org/10.1007/s10750-016-3007-0.
Location: Global analysis
Take home message: A pond's efficiency at retaining nutrients highly depends on topography, season, soils, climate, geology and hydrology. We need to understand how ponds function within a landscape - interconnectivity.
Threats: Small waterbodies are still under-represented in research and study. It is not fully understood how they function and so policy fails to protect them. Stressors of ponds are not fully understood. Ponds are threatened by intensive agriculture, developments and climate change.
Biodiversity: Ponds that are unpolluted ("clean water") are important for ecosystems and biodiversity. Ponds have been shown to hold a greater biodiversity at a landscape scale than other waterbodies such as rivers and lakes.
Carbon/climate: Ponds could trap as much carbon as the ocean (Downing, J., et al, 2008). However, evidence suggests that small ponds can also be net emitters of methane, under certain conditions. There could in fact be substantial methane emissions from the most abundant waterbody type: small ponds (Holgerson and Raymond, 2016).
Management: Small volumes (easily influenced by pollution due to inability to dilute) but small catchments (may escape pollution event). Be aware of the catchment of your pond and ensure that waterbodies are protected from sources of pollution. Historic natural disturbance can be replicated by low-intensity grazing regimes. Species assemblages can be damaged by physical management.
Specific figures: Estimating pond numbers is still difficult and there is no accepted number of global ponds. Estimates range from 64 million to 3 billion! Biggs et al. 2000, categorised 16 different types of ponds, based on macroinvertebrate assemblage data.
Research gaps: Basic surveys for assemblages such as micro-organisms, mosses, algae, semi-terrestrial invertebrates and other species are severely lacking. Studies have been focused on larger, more obvious invertebrates and amphibians. The best way to protect biodiversity in small waterbodies is unknown. How quickly do ponds undergo changes?

Paper 5.

Taylor, S. et al. (2019) 'High carbon burial rates by small ponds in the landscape', Frontiers in Ecology and the Environment, 17(1), pp. 25–31. Available at: https://doi.org/10.1002/fee.1988.
Location: UK
Take home message: Ponds can help mitigate carbon emissions.
Biodiversity: Juncus spp. associated with higher rates of carbon emissions in wetland environments.
Carbon/climate: Time taken for ponds to become carbon sinks are unknown. Ponds can emit methane and nitrous oxide, which may offset their carbon capture abilities. With warming and as the pond aged, emissions of methane increased. Actual carbon storage was on average 13.09% lower than estimated storage. But flux over 20 years = net storage of carbon.
Management: Shallow ponds emit more GHG. Vegetated ponds emit lower GHG. Value of late-successional stage ponds is overlooked. Restoration can remove valuable habitat and species. Better to create a new pond nearby and create a diverse pondscape.
Specific figures: Burial rate of carbon in ponds can be 20 – 30 times than other habitats such as woodlands and grasslands. Depending on vegetation, carbon burial rates can be 79–247 g m^2/yr, with an average of 142 g m^2/yr. 85% – 90% of phosphates, nitrates, and suspended sediments can be removed from watercourses if a small pond is constructed adjacent to it. Carbon dioxide flux was between emissions of 3792mg m^2/day and uptake of 641mg m-2 d-1. Organic carbon storage of mature ponds was 2564g OC m^2, but had a wide range of 1413 to 4459 g OC m^2. Young ponds (less than three years old): burial rates of 13.58g OC m^2/yr. But still more than temperate forests of 4.2g OC m^2/yr.
Method: 12 ponds of 18 or 20 years old. 3 ponds of 3 years old. 1m x 1m at 30cm deep and filled with water that day.

Paper 6.

Jeffries, M.J. et al. (2022) 'Organic carbon in British lowland ponds: estimating sediment stocks, possible practical benefits and significant unknowns', Hydrobiologia [Preprint]. Available at: https://doi.org/10.1007/s10750-022-04972-z.
Location: UK
Take home message: No significant relationship between sediment depth and carbon stock. Ponds can be a source and sink of GHG.
Threats: Warming temperatures.
Biodiversity: Benefits to pollinators, insectivorous birds, terrestrial spiders. Ponds are a biodiversity hotspot.
Carbon/climate: A source of methane gas emissions. As arctic ponds warm, CO2 and CH4 emissions will increase. Can rapidly switch from a source to a sink and back again. Drivers of GHG emissions remains unclear.
Management: Can be created easily and begin burying carbon in a year or two. But paper also states that carbon accumulation of new ponds is limited in the first 1-3 years.
Specific figures: Pond sediment can hold 9.38kg of organic carbon in a sediment block the size of $1m^2$ x 20cm. An estimated total of 2.63 million tonnes of OC across Great Britain stored in pond sediments, (Confidence Interval of 95% 1.41 to 3.84 million tons). 20.7mg C cm^3 to 74.4mg C cm^3.
Method: Two linked studies of lowland ponds in England. Carbon sticks in sediment and OC burial rates. 40 ponds in Northumberland plus three other locations. Vanadium steel corer. Total carbon – dry combustion Total Elemental Analysis. Range of vegetation communities. Some ponds were completely excavated.

Paper 11.

Robotham, J. et al. (2021) ‘Sediment and Nutrient Retention in Ponds on an Agricultural Stream: Evaluating Effectiveness for Diffuse Pollution Mitigation’, Water, 13(12), p. 1640. Available at: https://doi.org/10.3390/w13121640.
Location: UK
Take home message: Pond features covered less than 1% of land cover but captured 15% of sediment run off. Can help reduce downstream pollution.
Management: Spreading enriched sediment on the land could be a good soil conditioner.
Specific figures: 14 ponds trapped 83t (15% total) sediment, 122kg (10% total) phosphorus, 4.3t (8% total) organic carbon. Eight “offline” ponds stored 47.8t of sediment. Six “online” ponds 39t.
Method: NFM scheme in Oxfordshire. Constructed in 2018 and 2019. Sediment collected with a core. Dry bulk density calculated via loss through ignition method. Organic matter converted into organic carbon. 60 soil samples.

Paper 14.

Freer, A., et al. (2014) ‘The Effect of Water Oxygen Content on the Production of Greenhouse Gases from Shallow Pond Sediments’, Geophysical Research Abstracts, Vol. 16
Location: Cumbria, UK
Take home message: Anaerobic/anoxic conditions results in production of CO2 and CH4.
Carbon/climate: Carbon dioxide and methane gas produced when anaerobic conditions present in water. Abundance of nutrients with shallow water means eutrophic episodes during summer are common. Fluctuations in oxygen content of the water.
Method: Sediment cores. Agricultural pond system. Oxygen content of water manipulated between oxygenated and anaerobic on cores taken. GHG measurements (dissolved gas in water) taken.

Paper 19.

Smith, L.P. et al. (2022) 'An evidence-based study mapping the decline in freshwater ponds in the Severn Vale catchment in the UK between 1900 and 2019', Hydrobiologia, 849(21), pp. 4637–4649. Available at: https://doi.org/10.1007/s10750-022-05000-w.
Location: UK
Take home message: 57.7% decline in ponds between 1900 and 2019. Pond density declined from 7.3 ponds to 4.5 ponds km^2. 62.3% ponds lost from arable or pasture (agri). Ponds tend to be clustered.
Biodiversity: Support more species and scarce/IUCN species than rivers and lakes incl. birds, bats, pollinators.
Management: Agri land use change from permanent pasture to arable accounted for 43.9% of pond losses (2,747 ponds). But arable land most associated with pond creation.
Specific figures: Pond size $1m^2$ and 2ha. Figure-heavy paper. 480,000 ponds in the UK in 2007 (figures extrapolated). Covered approximately 190,000ha of land. 10,833 ponds on historic maps. 4,580 in present day maps. 57.7% loss. 2,048 new ponds created. Net loss of 38.8%.
Method: Used historic and present-day maps. Figures extrapolated.

Paper 22.

Gilbert, P.J. et al. (2021) 'Quantifying organic carbon storage in temperate pond sediments', Journal of Environmental Management, 280, p. 111698. Available at: https://doi.org/10.1016/j.jenvman.2020.111698.
Location: Northeast England, UK
Take home message: The rhizosphere may be an overlooked factor in determining the drivers of carbon storage in pond sediment.
Carbon/climate: Vegetation may play a role in methane emissions, through root exudates making carbon more available or less available. Ponds dry and become CO_2 sources within days as sediments react to the air. (Old) age of pond doesn't appear to play a factor in carbon sequestration.
Management: Highest carbon density found in ponds with the most diverse sward of wetland plants (48.8mg C cm^3).
Specific figures: Ponds of less $1000m^2$ make up 8.6% of global inland waters but 15.1% of CO_2 and 40% of diffused CH_4.
Method: 40 ponds in Northumberland. Corer. Moisture content and Dry Bulk Density.

Paper 26.

Davies, B. et al. (2009) 'Making agricultural landscapes more sustainable for freshwater biodiversity: a case study from southern England', Aquatic Conservation: Marine and Freshwater Ecosystems, 19(4), pp. 439–447. Available at: https://doi.org/10.1002/aqc.1007.
Location: UK
Take home message: Paper is more about protecting biodiversity in "reserves" rather than in segments across agricultural landscapes.
Threats: Buffer strips around ponds may not adequately protect the water column in a pond.
Biodiversity: At a landscape scale, pondscapes are the most biodiverse habitat, compared to rivers and ditches. On a site level, rivers have the greatest biodiversity.

Paper 27.

Palmer-Felgate, E.J. et al. (2013) 'How effective are reedbeds, ponds, restored and constructed wetlands at retaining nitrogen, phosphorus and suspended sediment from agricultural pollution in England?', Environmental Evidence, 2(1), p. 1. Available at: https://doi.org/10.1186/2047-2382-2-1.
Location: UK – lit review
Take home message: Method paper – no results
Carbon/climate: Research in the role of constructed and natural wetlands have inconsistent results. Whilst it is true that wetlands have been shown to retain sediment and nutrients, the opposite is also true, showing that wetlands may in fact increase sedimentation and nutrient loading to receiving waterbodies. Wetlands have been shown to become a source of phosphorus, from a sink, over a ten year period.
Method: 16 articles met criteria for data extraction. 43 wetlands in all – 33 constructed ponds, 10 natural ponds. 0.788m^2 to 40000m^2. Time of establishment ranged 0 – 15 years.

Paper 29.

Gilbert, P.J. et al. (2017) 'Quantifying rapid spatial and temporal variations of CO2 fluxes from small, lowland freshwater ponds', Hydrobiologia, 793(1), pp. 83–93. Available at: https://doi.org/10.1007/s10750-016-2855-y.
Location: Northumberland, UK
Take home message: Very good paper about carbon. It is difficult to generalise the role of ponds in carbon sequestration. In one study with 26 ponds in a small spatial area in Northumberland, UK, there was significant variability in carbon flux during a dry summer period. As ponds dry, they release CO_2 and a site can become a net emitter of carbon.
Biodiversity: GHG flux rates didn't vary across vegetation communities (opposite to paper 22 by Gilbert).
Carbon/climate: Became a net emitter of carbon after 12 days of drying.
Specific figures: Flux rates of CO2 varied greatly - net intake on Day 1 of 641 ± 1490 mg m^2 per day, to a net emission of 190 ± 1286 mg m^2 per day by Day 4.
Method: Monitored carbon flux in 26 ponds over a 2-week drying period. Ponds only a few metres apart. Floating chamber method collected CO2 flux.

Paper 31.

Yvon-Durocher, G. et al. (2017) 'Long-term warming amplifies shifts in the carbon cycle of experimental ponds', Nature Climate Change, 7(3), pp. 209–213. Available at: https://doi.org/10.1038/nclimate3229.
Location: Global literature review
Take home message: Warming results in increased methane emissions
Carbon/climate: Warming of ponds could accelerate climate change. Carbon balances can be altered from warming. After seven years of warming, a pond's ability to absorb CO_2 is halved. Methane emissions were up by 1.5 times after one year of warming and 2.5 times after seven years. Times where the greatest CO_2 absorption was found coincided with the greatest emissions of methane. Carbon dioxide can metabolise anaerobic respiration (of microorganisms), producing methane as a result.
Specific figures: Approximately 4% of the Earth's surface is lakes and ponds (not taking the glaciated surfaces into account). This small area contributes to a large amount of carbon dioxide and methane release. Ponds of less than 1000m^2 in size may, as a whole, contribute to 40% of inland water methane emissions.
Method: Experimental mecocosm – outdoor experiment. Not necessarily representative of natural ponds that receive inputs from the watershed. Water was warmed to 4-5oC above ambient temperature – is this currently realistic? The Relationship Between Air Temperature and Stream Temperature - NASA/ADS (harvard.edu)

Paper 35.

Hill, M.J. et al. (2021) 'Pond ecology and conservation: research priorities and knowledge gaps', Ecosphere, 12(12), p. e03853. Available at: https://doi.org/10.1002/ecs2.3853.
Location: Lit review
Take home message: Ponds should be thought of as part of a "waterscape" and not as individual entities. However, isolated ponds may be more protected from negative influences such as invasive species and pollution. Significant gaps in long-term studies that look at pond processes over time. Agricultural ponds are a significant habitat for sequestering carbon. Small ponds bury as much carbon as woodlands and grasslands, if not more. BUT Small ponds can be a sink and a source of GHG.
Threats: Nutrient pollution, run off. Urbanisation. Ponds used as pollution sinks to improve water quality downstream – but results in polluted ponds. Ponds with different functions. But maybe they are protecting water bodies e.g. streams with lower biodiversity than could be found in a good quality pond. Non-native species. Climate change. Ponds can store as much carbon, or more, than woodlands and grasslands. Connectivity vs. isolation.
Biodiversity: Often hold a higher biodiversity than lakes and rivers. Provides water, food, habitat for many aquatic and terrestrial species. Scrub and sediment removal increases bird diversity due to increased inverts as a food source. Predator spiders and beetles increase due to prey inverts. Birds feeding on aquatic inverts have higher omega-3 than birds feeding on terrestrial inverts. Omega-3 helps with physical and cognitive development. However, no knowledge on effects of pollution on nutritional val+ue. Leaf litter can provide food and nutrients for inverts.
Carbon/climate: Drought can increase the number of ephemeral ponds and species may be unable to adapt. This could impact the amount of GHG released from ponds.
Management: Trampling, grazing, around ponds slows succession, stimulates germination and dispersal.
Specific figures: 547 million – 3.19 billion ponds globally.

Paper 36.

Paper 36. Miracle, M. et al. (2010) 'Preface: Conservation of European ponds-current knowledge and future needs', Limnetica, 29, pp. 1–8. Available at: https://doi.org/10.23818/limn.29.01
Location: Europe
Take home message: Many knowledge gaps for ponds in comparison to other waterbodies. Overlooked in terms of percentage land coverage and contribution to the global carbon cycle. Mainly a review of other existing papers that have been read during this study.
Carbon/climate: Can store more carbon than lakes.
Management: EU WFD doesn't apply to waterbodies smaller than 50ha.

Paper 37.

Hill, M.J. et al. (2018) 'New policy directions for global pond conservation', Conservation Letters, 11(5), p. e12447. Available at: https://doi.org/10.1111/conl.12447.
Location: Global
Take home message: Conservation policy is failing to protect pondscapes. Management should be focussed on pond networks, not individual ponds.
Threats: Lack of knowledge and gaps in research.
Biodiversity: More valuable when ponds are in a pondscape, not in isolation. Many small ponds better than one large pond.
Management: Incentives must be enough to cover costs, otherwise ponds could be infilled.
Specific figures: At least 500 million global ponds

Paper 50.

Raebel, E. et al. (2012) 'Identifying high-quality pond habitats for Odonata in lowland England: Implications for agri-environment schemes', Insect Conservation and Diversity, 5. Available at: https://doi.org/10.1111/j.1752-4598.2011.00178.x.
Location: UK
Take home message: Good paper on most beneficial pond types for Odonata biodiversity. Ponds need to have more complex vegetation structures and clearer water for a greater population of Odonata. Species richness can depend on age of ponds and presence of buffer. A pondscape is better than ponds in isolation.
Threats: Ponds greater than 100m apart results in a large reduction in (40%) in species richness. It is important for the spatial ecology of ponds, "pondscapes", to be taken into account so there is the greatest benefit to biodiversity. Many small ponds together have a more beneficial impact than larger ponds, further apart.
Biodiversity: Ponds with floating and submerged vegetation had the greatest number of Odonata exuviae, followed by ponds with just floating vegetation. Ponds with no vegetation or just emergent vegetation had the lowest number of exuviae, suggesting these types of ponds hold the lowest Odonata populations. Ponds completely surrounded by trees are not favoured by Odonata and therefore these were not included in the study.
Management: Ponds that are turbid, that are older, and those that had dried out the year before all held a reduced number of exuviae. Transparent ponds may have better water quality, reduced pollution and reduced sedimentation, usually resulting in a greater abundance of exuviae – only if the pond didn't dry out the previous year. Ponds with buffers but without aquatic vegetation results in no exuviae. Buffers are only important for exuviae if aquatic plants are present and can increase species richness when Odonata are present.
Specific figures: 50% loss of ponds in 20th Century. 487,000 ponds now (Carey et al., 2008). Younger ponds (less than three years old) have a greater abundance of exuviae (up to 8 times more) but a reduced species richness than older ponds.
Method: 29 farmland ponds.

Paper 59.

Williams, D.D. (1997) 'Temporary ponds and their invertebrate communities', Aquatic Conservation: Marine and Freshwater Ecosystems, 7(2), pp. 105–117. Available at: https://doi.org/10.1002/(SICI)1099-0755(199706)7:2<105::AID-AQC222>3.0.CO;2-K.
Location: UK
Take home message: Temporary ponds are important to biodiversity but are at risk of being lost through drainage and "restoration".
Threats: Pond "improvement" schemes can be a threat to temporary, ephemeral ponds. Ponds drying out – loss of habitat "volume", warming of water. Drainage to bring land into cultivation.
Biodiversity: Temporary ponds can hold populations of rare species e.g. those which require a dry phase in their life cycle such as fairy shrimp and tadpole shrimp.
Carbon/climate: Temporary ponds have greater variation in their chemical and physical environment than nearby permanent ponds.
Management: Temporary ponds of differing varieties should be maintained in order to keep a high diversity of waterbodies.
Specific figures: 1986 – OS maps. 800k ponds.

Paper 61.

Wood, P.J., Greenwood, M.T. and Agnew, M.D. (2003) 'Pond biodiversity and habitat loss in the UK', Area, 35(2), pp. 206–216. Available at: https://doi.org/10.1111/1475-4762.00249.
Location: UK
Take home message: Pond number is unsure. Old ponds should be retained and new ones created. Temporary ponds are just as important for biodiversity than permanent ponds.
Threats: Greatest pond loss from 1975 – 1995? Net increase on pastoral land.
Biodiversity: The natterjack toad relies on ephemeral ponds in open early successional habitats for reproduction. Temporary ponds frequently have high floral and faunal biodiversity (Nicolet 2001).
Management: Maintaining diversity of ponds within a landscape is essential. Believing that maintaining open water by removing vegetation is very damaging.
Specific figures: Ponds: $1m^2$ to 2ha in size. The Lowland Pond Survey (1996) - lowland ponds in GB around 228,900. However, will be an underestimate. Errors: historical maps only identify ponds that were surveyed at that time (some may have been missed); survey will not capture all sites, bias towards larger ponds; ephemeral ponds overlooked; the number of garden ponds in the urban environment has never been estimated.

Paper 63.

Chester, E.T. and Robson, B.J. (2013) 'Anthropogenic refuges for freshwater biodiversity: Their ecological characteristics and management', Biological Conservation, 166, pp. 64–75. Available at: https://doi.org/10.1016/j.biocon.2013.06.016.
Location: Lit review – Australia funded
Take home message: Reconciliation ecology – supporting biodiversity in heavily disturbed/modified landscapes.
Threats: Biodiversity value of man-made ponds in highly disturbed e.g. agricultural landscapes is not fully appreciated.
Biodiversity: Refuges can be an important source of "species colonists" to the wider landscape if and when disturbance stops. Areas outside of "protected areas" have a lot of value.
Method: Lit review including non-digitised papers.

Paper 64.

Riley, W.D. et al. (2018) 'Small Water Bodies in Great Britain and Ireland: Ecosystem function, human-generated degradation, and options for restorative action', Science of The Total Environment, 645, pp. 1598–1616. Available at: https://doi.org/10.1016/j.scitotenv.2018.07.243.
Location: UK (Rothamsted Research for Defra)
Take home message: Restore hydrological functioning. Restore and manage riparian zone. Manage activities in the wider catchment. Actions with multiple benefits.
Threats: Invasives, non-natives, climate change, industrial pollution, intensive agriculture etc. Farmer opinion and incentives. Payment schemes.
Biodiversity: Birds, inverts, small mammals, native plants all mentioned in terms of impacts on them.
Management: Shading prevents water from getting too warm. Sedimentation from agricultural soils impacts negatively on invertebrate communities. Create buffer zones to protect from landscape pressures. No single approach that can be applied to all Small Water Bodies. Restoration may be beneficial for some outcomes and not others. Restoration – what are the reasons for degradation in the first place? No "one size fits all" fix. Look at a catchment scale and accept trade-offs. Improve resilience.
Specific figures: Between the 19th Century and the 1980s, total number of ponds decreased by about 75%. Excluding garden ponds but including those not within an agricultural setting, there are half a million ponds in Great Britain (Williams et al., 2010).

Depending on the North Atlantic Oscillation, headwater temperatures in UK winters can vary by 3-6°C.
Method: Lit review.

Paper 67.

Ruse, L.P. et al. (2018) 'Consequences of pond management for chironomid assemblages and diversity in English farmland ponds: Consequences of pond management for chironomid assemblages', Journal of Limnology, 77(s1). Available at: https://doi.org/10.4081/jlimnol.2018.1789.
Location: UK, Norfolk
Take home message: Pond restoration increases chironomid species number.
Biodiversity: Managed ponds possess a greater number of macrophyte, bird and invertebrate species.
Method: 2 ponds restored. One left as a control. Sampled multiple times before and after restoration. (Non-biting midges).

Paper 69.

Moss, B. (2014) 'Fresh Waters, Climate Change and UK Nature Conservation', Freshwater Reviews, 7. Available at: https://doi.org/10.1608/FRJ-7.1.789.
Location: UK
Take home message: Large overview
Threats: Changes in hydrology may have a greater impact on species than temperature changes.
Biodiversity: Zooplankton have been shown to rapidly genetically adjust to warming water temperatures.

Paper 73.

Paper 73. Biggs, J. et al. (2005) '15 Years of Pond Assessment in Britain: Results and Lessons Learned from the Work of Pond Conservation', Aquatic Conservation: Marine and Freshwater Ecosystems, 15, pp. 693–714. Available at: https://doi.org/10.1002/aqc.745.
Location: UK
Take home message: Ponds misunderstood and under-represented in policy.
Threats: Small catchment sizes – beneficial as can be protected from pollution, but if polluted, little chance of dilution to offset it. Comparatively small waterbody.
Biodiversity: On a UK scale, ponds hold a greater diversity of macroinvertebrates than rivers. They also support more uncommon species.

Ponds are incredibly valuable for species such as amphibians and water beetles (see Balfour-Browne, 1962; Foster and Eyre, 1992; Swan and Oldham, 1989).
Specific figures: Pond Conservation began in 1986 and the UK National Pond Survey began in 1989.

Paper 74.

Davies, B.R. et al. (2008) 'A comparison of the catchment sizes of rivers, streams, ponds, ditches and lakes: implications for protecting aquatic biodiversity in an agricultural landscape', Hydrobiologia, 597(1), pp. 7–17. Available at: https://doi.org/10.1007/s10750-007-9227-6.
Location: UK
Take home message: Ponds as a pondscape hold a higher biodiversity than other wetland types
Biodiversity: Ponds were the most common waterbody type, but covered the smallest surface area. Despite this, ponds held the greatest number of plants and macroinvertebrates compared to the studied rivers, lakes, streams and ditches.
Specific figures: Pond sites supported 238 species, more than 10% more than the next most numerous waterbody type (rivers with 201 species). Also had the greatest species rarity index.
Method: 13x11km study area of lowland agriculture in England. 75% arable land. Pond size 25m^2 – 2ha

Paper 75.

Williams, P. et al. (2020) 'Nature based measures increase freshwater biodiversity in agricultural catchments', Biological Conservation, 244, p. 108515. Available at: https://doi.org/10.1016/j.biocon.2020.108515.
Location: UK
Take home message: Ponds have a disproportionate, positive effect on biodiversity within an agricultural landscape. Creation of ponds can mitigate against biodiversity losses elsewhere.
Threats: Pollution.
Biodiversity: Creating "clean water ponds" - offline and unpolluted – were shown to increase biodiversity in the area by 26%.
Method: Nine-year study. Streams, ponds and ditches. Midlands.

Paper 76.

Sayer, C. et al. (2012) 'The role of pond management for biodiversity conservation in an agricultural landscape', Aquatic Conservation: Marine and Freshwater Ecosystems, 22(5), pp. 626–638. Available at: https://doi.org/10.1002/aqc.2254.
Location: UK
Take home message: Ponds should be managed.
Threats: Increasing spatial isolation between ponds. Since WW2, many ponds were infilled due to agricultural intensification. The consequences of pond succession on biology is not very well studied and it is unsure whether different communities of plants and animals utilise different stages of pond.
Biodiversity: Heavily shaded ponds were shown to have a low species richness.
Management: There is no clear message regarding the value of pond management. Recolonising of a range of species can occur quickly (1-2 years), either because they survive the disturbance of management or they can disperse from other nearby, unmanaged ponds.

Paper 78.

Cereghino, R., et al., (2008), 'Biodiversity and distribution patterns of freshwater invertebrates in farm ponds of a south-western French agricultural landscape', Hydrobiologia, volume 597, pp. 43–51
Location: France
Take home message: Depending on the invertebrate families studied, ponds may be more or less beneficial to communities than rivers. Early mid-successional ponds provide the greatest species biodiversity.
Threats: Infilling and pollution.
Biodiversity: There was limited evidence to suggest that use of the pond had an impact upon invertebrate community. Ponds have a large contribution to local biodiversity, despite their small size. Ponds at an early-mid successional stage support the greatest number of species, likely due to the less prevalence of emergent plants. In this study, an intermediate successional stage is described as a pond that has less than 25% emergent vegetation and 20-50% of submerged vegetation. "Abandoned" ponds were also the largest, so species diversity may have also been linked to size and habitat diversity
Management: Ponds that were unmanaged and which underwent natural succession tended to hold a greater number of species. Permanent abandonment would lead to eventual terrestrialisation of ponds, negatively affecting populations of aquatic fauna.
Specific figures: It is estimated that ponds outnumber lakes 100:1.

Method: 36 farm ponds – 27 used and 9 abandoned. Habitat variables recorded. Surveyed in March and July. Sampled eight times? Also surveyed in winter? Also surveyed rivers.

Paper 79.

Walton, R. E. et al. (2020) 'Open-canopy ponds benefit diurnal pollinator communities in an agricultural landscape: implications for farmland pond management', Insect Conservation and Diversity, 14(3), pp. 307–324. Available at: https://doi.org/10.1111/icad.12452.
Location: UK, Norfolk
Take home message: Removing woody vegetation from around a pond edge increases the abundance of pollinator communities.
Threats: Pond management declined from the 1960s and has resulted in many ponds becoming overgrown. Lack of research on benefits of terrestrialised and overgrown ponds. Terrestrial species could be lost through management.
Biodiversity: Diverse vegetation is linked with diverse pollinator communities.
Management: Biodiversity of freshwater can be enhanced through sediment removal and canopy management to reduce shading. A pondscape, with ponds at different successional stages, is important. Open-canopy ponds (usually early-successional) are important for pollinators e.g. bees, as food plants/flowers have the chance to persist. Not much is known about the effects of pond restoration on terrestrial invertebrate species. Leaving deadwood and plant matter around marginal pond habitat can provide nesting habitat for pollinators/hymenoptera. Management of encroaching woody vegetation improves pollinator communities. This should be done on a landscape scale to create heterogeneity.
Method: Nine farmland ponds in Norfolk

Paper 82.

Hill, M.J. et al. (2016) 'Macroinvertebrate diversity in urban and rural ponds: Implications for freshwater biodiversity conservation', Biological Conservation, 201, pp. 50–59. Available at: https://doi.org/10.1016/j.biocon.2016.06.027.
Location: UK
Take home message: Pondscapes should be afforded policy protection rather than individual ponds. Individual ponds can have a varying contribution to local biodiversity but on a landscape scale, they are highly beneficial.
Threats: Infilling, lack of policy protection, pollution/habitat degradation. Current protection relies on presence of rare species in individual ponds. Surveys are a point in time snapshot – a pond surveyed as not high value because of absence of a rare species may indeed hold a rare species the next year, but is not policy protected.
Biodiversity: On an individual scale, pond "importance" and species diversity can vary, but on a landscape scale, they are of high importance to biodiversity. Floodplain ponds had a greater biodiversity than arable ponds. This could be due to their management e.g. managed for biodiversity, location to other waterbodies/corridors, reduced human disturbance.
Management: The Wildlife Trusts Living Landscapes – conserving areas outside of nature reserves. Million Ponds Project – 50-year creation of 500,000 ponds to complement the existing 500,000. Shading is one of the main causes of a poor pond habitat quality. Reconciliation ecology (Rosenzweig, 2003).
Specific figures: Ponds 25m^2 to 2ha (from Williams et al 2010). 5 out of 15 arable ponds had one or more inverts that were designated of conservation importance.
Method: 91 lowland ponds in floodplain meadow, arable, and urban

Paper 83.

Davies, S.R. et al. (2016) 'A new role for pond management in farmland bird conservation', Agriculture, Ecosystems & Environment, 233, pp. 179–191. Available at: https://doi.org/10.1016/j.agee.2016.09.005.
Location: UK
Take home message: Mosaic of pond diversity is essential. Open ponds tend to have more heterogenous habitat, resulting in greater bird species diversity (e.g. increased feeding opportunity).
Biodiversity: Whilst some birds preferred overgrown ponds, the greatest diversity and visit occurrence occurred at open canopy ponds. Heterogeneity in habitats is most beneficial. Agricultural landscapes becoming more homogenised since the 1940s has led to a reduction in biodiversity. Open-canopy ponds held more bird species of conservation concern (nine) than closed-canopy ponds (two). Some bird species were only found in overgrown ponds (great spotted woodpecker, treecreeper and nuthatch), evidencing the need for a pondscape mosaic. Open ponds provide feeding habitat in the form of aquatic insects. The most bird-biodiverse ponds were also the largest ponds, and also had the greatest aquatic macrophyte diversity. It is important that ponds hold a range of aquatic vegetation as this provides feeding and nesting habitat. This is true for waterbirds and other farmland birds. Overgrown ponds tend to have a more homogenous habitat which may be a cause of the reduced bird species diversity.
Management: Since the 1960s, many more farmland ponds have become terrestrialised. Ponds are becoming smaller and shallower as they transition into wet woodland. Invertebrate diversity continues to increase for 3-5 years after pond management. However, this is with the exception of molluscs, whose diversity was greatest in unmanaged ponds. Overgrown ponds could be categorised as a type of woodland fragment, which allows species to disperse between larger parcels of woodland. They still have a value.
Specific figures: 58 breeding bird species identified across 22 ponds.
Method: Farmland bird surveys undertaken on recently managed, open, aquatic plant-dominated ponds and overgrown, terrestrialised ponds with no aquatic plants. Diversity, abundance and composition monitored.

Paper 88.

Walton, R.E. et al. (2021) 'Once a pond in time: employing palaeoecology to inform farmland pond restoration', Restoration Ecology, 29(1), p. e13301. Available at: https://doi.org/10.1111/rec.13301.
Location: UK
Take home message: The reason for restoration needs to be decided and surveys should be carried.
Biodiversity: Biodiversity is increased when woody vegetation management and desilting occurs.
Management: Surveying is essential – rare aquatic plant species may not recolonise after restoration. Ponds can become terrestrialised within 20–30 years without management. This suggests that there has historically been management of ponds in the past.
Specific figures: Ponds can become terrestrialised within 20–30 years without management.
Method: A paleoecological study of plant and animal macrofossils for the Bodham Mystery Pit. One 124cm core taken, split into 1cm sub samples.

Paper 91.

Alderton, E. et al. (2019) 'Ghost ponds' – How to resurrect in-filled farmland ponds to assist aquatic biodiversity conservation in agricultural landscapes. Available at: https://doi.org/10.1101/831859.
Location: UK
Take home message: Ghost ponds are an important part of freshwater biodiversity in the agricultural landscape and these should be picked for restoration, alongside the restoration and creation of new ponds.
Biodiversity: Ponds are important for landscape-scale biodiversity. Ghost ponds can retain a seedbank for over a century. They can recolonise a pond within six months of restoration. Water beetles (Coleoptera) are one of the first species types to colonise new ponds. Stoneworts (Chara) and pondweed (Potamogeton) both colonised. May be algae dominated in the first year. Colonisation rapidity can depend on flight-season for many inverts. Biodiversity for ghost ponds can be the same as restored extant ponds. Ghost ponds could be a viable seedbank for scarce or extinct plants.
Management: The creation of new ponds and restoration of existing ponds are both important management tools. Locate lost ponds on historic maps and aerial photography. Tithe. Usually visible on the ground as damp depressions. Crop maturation may be at a different rate than the surrounding area. Wet depressions may not be ghost ponds e.g. dry pits or old field drains. Ploughing can change the shape and size of the depression – may not be easily visible on the ground. DEM – Digital elevation model. Create

new ponds by restoring ghost ponds – can be a valuable biodiversity asset with a "built-in" seed source.

Specific figures:
Within the previous century, over 50% of ponds within UK farmland have been lost (Hassell, 2014). 28% of ponds lost in Norfolk since 1950s.

Paper 94.

Gee, J.H.R. et al. (1997) 'The ecological basis of freshwater pond management for biodiversity', Aquatic Conservation: Marine and Freshwater Ecosystems, 7(2), pp. 91–104. Available at: https://doi.org/10.1002/(SICI)1099-0755(199706)7:2<91::AID-AQC221>3.0.CO;2-O.

Location: UK

Take home message:
Vegetation cover has a bigger impact on invert diversity than pond size. Ponds are important for local biodiversity. Loss can result in regional loss of species. No correlation between presence of fish and inverts (small study). Ponds benefit from being close to each other.

Threats:
Drawbacks to research – species lists not comprehensive and ponds not necessarily representative.

Biodiversity:
Vegetation cover increases with time. The more vegetation, the more species richness of invertebrates and plants.
If a pond was at least one year old, its species diversity of plants and inverts was similar to older ponds (if connected to an adjacent wetland).
Biodiversity of isolated ponds may increase over time as colonisation occurs.
A partially shaded pond can increase diversity of emergent and floating/submerged plants, up to a point. More trees results in fewer Odonata?
Presence of ponds within a farmed landscape increases the diversity and population size of breeding birds.
Loss of ponds results in loss of local biodiversity and gene "pools". Extrapolated – a threat to regional and national populations due to widescale loss.
Pond area has less of an impact on invert diversity than vegetated area of pond.

Management:
A number of small ponds, even two, is probably more beneficial for biodiversity than one large pond.
A low stocking density of salmonids may not impact invert or plant diversity.
Ponds should be restored and created. Inevitable that some ponds will be lost due to land use change of agricultural to development land.
Terrestrialisation of ponds is a natural fate. All stages of pond succession has value and restoring ponds on a wide scale is undesirable. Creation is better.
A large proportion of floating plants can reduce dissolved oxygen concentration in the water column.
No single management technique or policy will be of benefit to all organisms.

Specific figures:
Between 1984 and 1990, it is estimated that between 4% and 11.5% of ponds were lost in the UK (agri or general?) Barr et al, 1994

Method:
Database of 650 ponds in Dyfed and Powys. 400 had addresses. One third completed survey. 51 ponds were selected for survey from questionnaire.
Macrophyte and macroinvert surveys of 51 new and restored ponds in Wales.

Paper 110.

Lewis-Phillips, J. et al. (2019) 'Seasonal benefits of farmland pond management for birds', Bird Study, 66, pp. 342–352. Available at: https://doi.org/10.1080/00063657.2019.1688762.
Location: Norfolk, UK
Take home message: Greater bird diversity at open-canopy farmland ponds.
Biodiversity: Terrestrialised ponds can possess a lot of deadwood (KB – this would be beneficial to a number of particular species). Bramble is an important feature for breeding birds – the larger the area of bramble, the greater the bird abundance. Warblers (apart from the chiffchaff) were absent or seen in reduced number at overgrown ponds. Passerine generalists e.g. blue tit, robin, blackbird as common at overgrown and managed ponds, slightly more at managed. Birds of conservation priority including yellowhammer and spotted flycatcher only seen at open canopy ponds. Woodcock and brambling were only present at overgrown ponds in winter. Open canopy may provide more feeding opportunities e.g. inverts and seeds. Open food source next to covered breeding area (bramble).
Management: There has been a low uptake of pond management options under previous agri-environment schemes (Natural England, 2009 – GR4). Ponds have become terrestrialised over the last 30-40 years due to a decline in pond management practices. Less shading = more macrophyte diversity = more inverts = more food for birds. Tree removal from margins can create a wet, muddy margin, which could further enhance the inverts available as a food source for e.g. snipe. Some species have also been known to collect materials for bird nesting from muddy margins. Birds like trees next to non-shaded water, not trees that create shaded water. Creating a mosaic/pondscape of open water, adjacent/nearby trees, bramble for nesting, low scrub and tall grasses is the most beneficial combination for breeding birds.
Method: Overgrown and open-canopy ponds surveyed in breeding season, post-breeding and winter. Open-canopy – restored within last 5 years. Less than 10% shading. Unmanaged – no management for 20-40 years. Over 85% shading. All ponds had a herbaceous margin over 7m wide. Average 1.5m deep. Minimum distance between ponds of 200m was chosen (remove spatial similarities).

Paper 112.

Lewis-Phillips, J. et al. (2020) 'Ponds as insect chimneys: Restoring overgrown farmland ponds benefits birds through elevated productivity of emerging aquatic insects', Biological Conservation, 241, p. 108253. Available at: https://doi.org/10.1016/j.biocon.2019.108253.
Location: UK
Take home message: Similar to 110. Open-canopy ponds are a good source of aquatic inverts which is good for feeding chicks post-breeding
Biodiversity: Pond restoration increases bird abundance by increasing abundance of insects. Odonata favour open-canopy ponds with plants suitable for ovipositing. Aquatic insects are of higher nutritional value than terrestrial insects due to their increased level of omega-3, which is beneficial for chick development. Open-canopy ponds in farmland landscapes are beneficial to insectivorous birds.
Carbon/climate: Flies (Diptera) have a tolerance for a wide range of temperatures of water (Cornette et al., 2015).
Management: Landscape-scale approach.

Paper 115.

Quigley, A. J., (2017) 'Impact of nearby agricultural fertilizer application on nutrient content of freshwater ponds at Naphill Common, Buckinghamshire.', Canterbury, Christ Church University
Location: UK
Take home message: Chemistry-heavy. Oxidised nitrogen correlated with distance from farm. Polluted pond waters can affect persistence of great crested newt. But cannot dredge polluted pond due to EU Habitats Directive?
Threats: Ponds' value as providing ecosystem services and biodiversity gains are not appreciated. High nutrient inputs, including nitrogen (run-off), can cause algal blooms in ponds and a greatly reduced level of dissolved oxygen. No significant relationship observed between phosphate or ammonia concentration in pond water and distance from agricultural land, even though phosphate levels varied widely from 60 ug/L to 1025ug/L. High pollution can affect a number of species including great crested newt.
Biodiversity: High level of biodiversity to area ratio.
Specific figures: 400,000 ponds covering 14% of the UK (Bailey-Watts et al., 2000),
Method: Nutrient levels of five natural ponds.

Paper 124.

Walton, R.E. et al. (2021) 'Improving the pollinator pantry: Restoration and management of open farmland ponds enhances the complexity of plant-pollinator networks', Agriculture, Ecosystems & Environment, 320, p. 107611. Available at: https://doi.org/10.1016/j.agee.2021.107611.
Location: UK
Take home message: Ponds are an important food source for pollinators.
Biodiversity: Ponds are an important food source for pollinators. The presence of ponds improves the "forage network" for pollinators. Overgrown ponds hold similar plant communities to adjacent farmland and so overgrown ponds do not particularly add anything of species diversity value, compared to recently restored or managed ponds. The presence of bramble and thistle, both sources of food for pollinators, were an important part of the landscape for pollinators. These were present to a greater extent at the managed ponds, possibly due to the increased ground disturbance. Water mint is a late summer flowering plant, providing an important nectar source for later in the season. This plant is associated with ponds with an open canopy.
Management: Late-successional ponds have the lowest macrophyte diversity.
Method: How bees, butterflies and hoverflies are affected by pond management. Nine farmland ponds.

Paper 137.

Rabaey, J. and Cotner, J. (2022) 'Pond greenhouse gas emissions controlled by duckweed coverage', Frontiers in Environmental Science, 10. Available at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.889289
Location: Minnesota, USA
Take home message: Greenhouse gas emissions from ponds are highly variable.
Carbon/climate: Ponds and other freshwaters are known to contribute a significant amount to global CO2, CH4 and N2O emissions. Emissions measured from ponds have varied greatly. Ponds with duckweed had higher emissions.
Method: Measured 26 ponds for CH4, CO2 and N2O. Ponds had a variety of uses.

Paper 144.

Biggs, J., et al. (1994), 'New Approaches to the Management of Ponds', British Wildlife, 5 (5), pp. 273 – 287
Location: UK
Take home message: Overgrown ponds are not detrimental. Everything has a value.
Biodiversity: As the successional stage of ponds progress, species community will change but not necessarily reduce in conservation value. Different invertebrate assemblages present in deeper, permanent ponds compared to shallower, ephemeral ponds. Emergent plant species especially valuable.
Carbon/climate: Climate change. Temporary ponds which dry out every year may be more stable and have greater longevity than permanent ponds due to potentially reduced siltation.
Management: Natural ponds are often shallow and vary widely in size. Succession and terrestrialisation of ponds is a natural process. Considerations: Will species benefit from desilting? What successional stage is it currently in? Restoring a late-succession pond may not be appropriate as species could be lost. Temporary ponds are at risk of over-management as they can look uninteresting and may be dug out to create permanent water. Communities favouring ephemeral conditions can be lost through this action. An overgrown pond with 100% plant cover contained 40 plant species. Trees around a pond is not a bad thing, partial shade can be beneficial, and decaying wood and leaf litter can be utilised by species. If grazing has stopped and saplings have grown, then tree management would be suitable. Aquatic plants are valuable habitat for species and are important in their own right. Ponds being "choked" is not necessarily a bad thing. If vegetation is to be removed from a pond, then removing a "slice" so that it includes shallower and deeper water vegetation would be most beneficial. Removing homogenous areas of vegetation to an extent, could increase diversity of plant species. Grazing can prevent tall grasses from dominating and the muddy margins created by footfall can be a niche habitat in themselves. Over-grazing should be avoided. Unaesthetically pleasing ponds are still valuable. There is no "ideal" pond, a mosaic is needed.
Specific figures: Used definition of a pond is 1m2 and 2ha in size and which holds water for at least four out of 12 months. – They used def. from Pond Conservation Group 1993.

Paper 145.

Biggs, J. et al. (2001) 'Dangers and opportunities in managing temporary ponds', Special topic, European Temporary Ponds: A Threatened Habitat, Freshwater Forum, p. 17.
Location: UK
Take home message: Temporary ponds are an important landscape feature, and their importance has been overlooked. They should be left to their own natural processes.
Threats: Management of temporary ponds tends to be focussed on one species e.g. natterjack toad or a water beetle. Some ephemeral ponds have been lost due to agricultural land drainage. Some ephemeral ponds are at risk of being lost by "restoration" – being made deeper and flooded. Connecting temp ponds to a ditch or stream to keep it wetter for longer can cause water pollution in the pond. Can increase sedimentation and reduce prevalence of plant species that persist in bare ground etc.
Management: Purpose of management should be clear. Pond water level and duration may vary year-on-year and benefit certain species in a certain year, but general ecology of the pond should not be affected, unless long-term changes occur. In general, leave temporary ponds alone, or deepen only very slightly. Create a deeper pond nearby – but frogs and GCN will predate on natterjack toad tadpoles if present. Bare ground/poaching by livestock is often beneficial. Try and maintain a margin around the pond that is not intensively managed.

Paper 146.

Sayer, C. et al. (2013) 'Managing Britain's ponds – conservation lessons from a Norfolk farm', British Wildlife, 25, pp. 21–28.
Location: Norfolk, UK
Take home message: Cannot dig enough new ponds to keep pace with terrestrialisation of old ponds. Lack of land "available" on productive agricultural land. Pond biodiversity responds positively to management.
Threats: Undermanagement – ponds would historically have been disturbed by large herbivores, weather events etc.
Biodiversity: Some species only occurred in single ponds, highlighting need for a mosaic of ponds, not ponds in isolation.
Management: Manage on rotation to create heterogeneity of a pondscape. Cut trees and shrubs to prevent overshading and remove half the silt.
Specific figures: Species diversity peaked 3-5 years after management.
Method: 24 ponds surveyed for aquatic plants, water beetles, snails, mayflies, damselflies. Split into "time since management" groups.