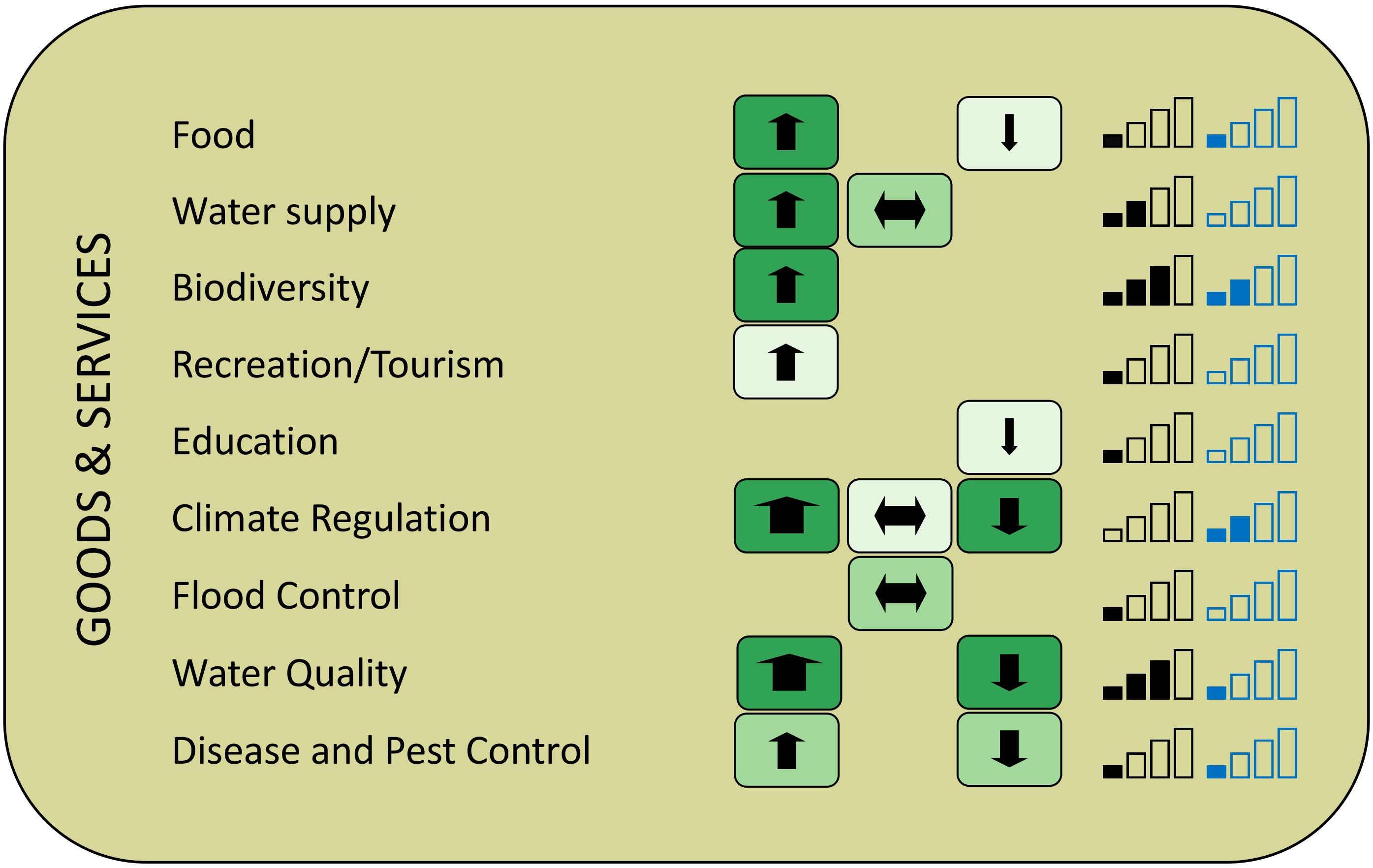
Allow re-flooding of previously flooded land or create new artificial wetlands.

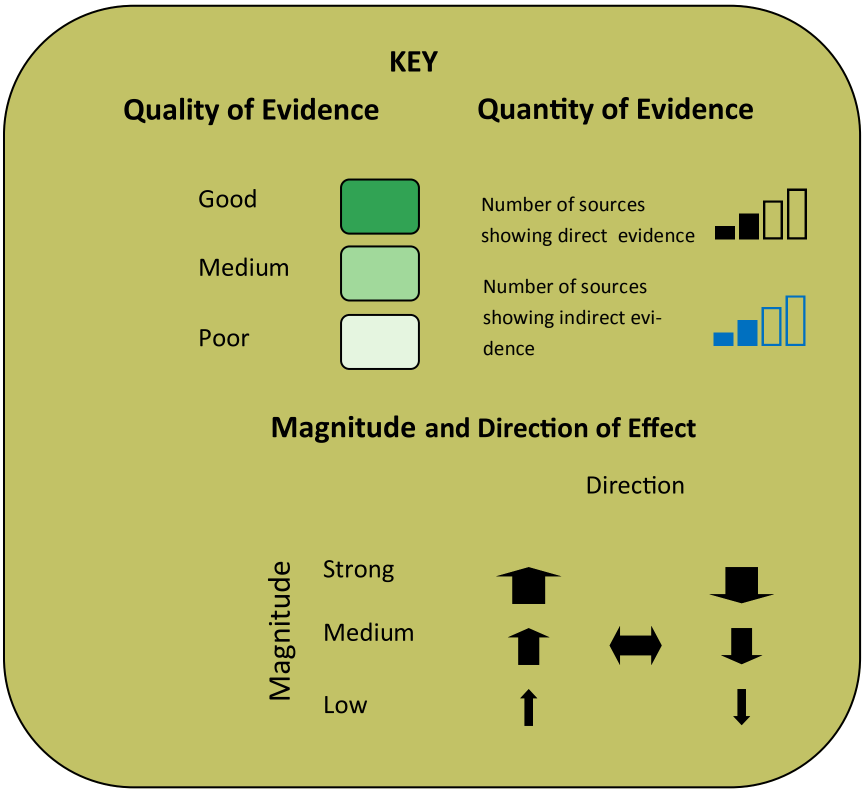


These pages represent a review of the available evidence linking management of habitats with the ecosystem services they provide. It is a review of the published peer-reviewed literature and does not include grey literature or expert opinion. There may be significant gaps in the data if no published work within the selection criteria or geographical range exists. These pages do not provide advice, only review the outcome of what has been studied.

Full data are available in electronic form from the Evidence Spreadsheet.

Data are correct to March 2015.

KEY



MANAGING ECOSYSTEM SERVICES

FRESHWATER

RESTORE WETLANDS

Provisioning Services—providing goods that people can use.

Cultural Services—contributing to health, wellbeing and happiness.

Regulating Services—maintaining a healthy, diverse and functioning environment.

PROVISIONING

Food: ***Strong Evidence***:-A study from the Somerset Levels found strong evidence that hay from areas with raised water levels was sub-optimal for nutrients for cattle forage, and was also lower in yield by 10%, though yields were more consistent from year to year[1]. ***Moderate Evidence:-*** A study from the USA found evidence that permanent water in impoundments created as part of watershed management had slightly higher levels of wildfowl than seasonally flooded areas[2]. ***Weak evidence:-*** An additional study from the USA found that restored wetlands at brackish water sites are beneficial for salmonid fish[3].

Water Supply: *Strong evidence:-* A meta analysis of studies from around the world shows that wetlands can reduce the downstream flow of water during dry periods, and can also increase evaporation[4] . The ability of this water to recharge aquifers depends however on the underlying geology. The conclusions are that wetlands (created or natural) do not necessarily improve the potential water supply of a catchment but that it depends on the geology.

CULTURAL

Biodiversity: ***Strong Evidence:-***— A study from Wales on the river Pelenna, which had an impoverished ecology due to mine-water pollution, demonstrated that the construction of artificial wetlands can benefit biodiversity where a wetland constructed to intercept mine-water run-off resulted in increased invertebrate, trout and bird populations in the local area[5]. In the USA, there is evidence that restored wetlands can provide high diversity of waterfowl within a few years of contsruction[6]. The water-bird diversity is influenced largely by total site area, while total species richness and diversity is more influenced by vegetation characteristics which can take many more years to develop. Similarly, a study of over 100 small restored wetlands in Canada shows that restored wetlands can have higher numbers of waterfowl than reference natural wetlands[7]. The size of a site is not always an important predictor of biodiversity as small water-bodies, especially ponds, can make the greatest contribution to regional aquatic biodiversity in lowland England[8]. ***Moderate Evidence:-*** Despite an increase in the area of available wetland in the UK, snipe populations continue to fall, suggesting that wetland creation may not benefit this particular species[9]. A study from the USA showed that restored or created coastal wetlands had the same or higher bird diversity than natural sites[10]. A comparison of 39 restored and 39 natural wetlands in the USA found no difference in bird diversity between natural and restored sites[11]. **Weak Evidence:-** A large meta-analysis of wetland creation projects in the USA shows that less than 50% can be considered successful in terms of aquatic macrophyte presence, and often have high numbers of non-native species[12].

Recreation/Tourism: ***Moderate Evidence:-*** Fishing contributes an estimated £1 billion to the UK rural economy, with £23 million generated from rod fishing licenses[13]. There is an implied link that wetland creation will benefit the fishing industry. On the Somerset levels, 70,000 people annually visit bird reserves, suggesting a link between wetland creation and tourism[1].

Education—There is weak evidence from Wales that there may be conflict of interest between the enhancement of wetland features for the conservation of biodiversity and the preservation of archaeological remains which are of benefit for future scientific study and education. This is largely based on the risks from conservation enhancements to existing water-bodies that preserve archaeological remains [14].

REGULATING

Climate Regulation: ***Strong Evidence:-*** Recreating wetlands from areas with high soil organic carbon such as former peat workings has benefits and costs. A study tracking restoration of a peatland showed that pre-restoration it acted as a carbon dioxide (CO_2) source, while two years post-restoration it had returned to being a carbon sink[15]. Methane emissions however are shown to increase in the short term when former drained peat agro-ecosystems are returned to natural conditions[1]. Peatland restoration through flooding can lead to the release of high levels of CO_2 and methane (CH_4) from the initial flooding due to the decomposition of organic matter on the surface[16]. The balance of greenhouse gas emissions/sinks is highly dependent on the water table level and management with a study from Germany showing that minerotrophic fen systems released nitrous oxide (N_2O) and CH_4 when water tables were high[17]. Lowering or raising the water table level by 5cm can affect the CH_4 emission levels by as much as 30-50% for wet grasslands on peat soils[18]. The aboveground biomass of sedges appears to influence the release of methane by stimulating the transport of CH_4 to the surface[19]. ***Moderate Evidence:-*** A laboratory study confirmed the potential for newly inundated high carbon soils to produce CO_2 and CH_4. It found that flooded peat was relatively inert but that greenhouse gas production can be significantly increased where plant material in the form of roots is present. This has implications for the flooding of vegetated areas[20]. However, there is some evidence that the restoration of forestry-drained peat-lands results in less methane than expected due to the poor establishment of methanogens (methane producing micro-organisms) even 10-12 years following restoration[21]. A study from the temperate USA has found evidence that newly created wetlands only achieved 50% of the soil organic matter and bulk density of natural wetlands 55 years after restoration[22]. The same authors also found that addition of organic matter can increase soil carbon. These additions however did not affect vegetation biomass which recovered to levels similar to natural wetlands within two years of restoration. A study from Austria shows that riparian forests in floodplains (and by extension, created wetlands with reforestations) have a large potential for carbon storage in soils, with up to 354 t ha^{-1} within 1m below the surface[23].

Flood Control: ***Moderate Evidence:-*** An economic study of the benefits of wetland creation to alleviate flooding in North Dakota USA found that it was not an economically viable solution over a 20 year time scale. Peak flood stage and flood damage would need to be reduced by 3.3-8% in order for the scheme to break even[24].

REGULATING

Water Quality:- ***Strong evidence:-*** Wetlands may be constructed either specifically to remove pollutants or have pollution control as an incidental aspect of their creation. In a structured system in the USA with cells of free wetland, phosphorous adsorption filters and vegetated strip, receiving municipal run-off water, all cells reduced nitrogen, suspended solids, biological oxygen demand, ammonia, phosphorus and *E. coli* bacteria[25]. Less structured more natural systems in the USA such as those receiving agricultural run-off and consisting of *Phragmites australis* and *Typha latifolia* also retain up to 100% nitrogen run-off, denitrifying 0-12% of incoming nitrogen, or retaining 66-100% of nitrogen in plant material[26]. Wetlands have shown to be useful in removing specific pollutants, such as iron from abandoned coalmines, removing 82-96% of incoming iron from a South Wales coalmine[27]. A risk of creating wetlands from previous agricultural land is that re-wetting can cause a pulse of released phosphorus which was previously in a bound state. This may affect downstream, water quality, with up to 2.5 times the amount of phosphorus leaving a restored system in North Carolina than an equivalent agricultural system[28]. This effect is particularly pronounced where the soil layers are of degraded peat[29]. The same restored North Carolina system did show that while newly created wetlands can be a net exporter of dissolved organic nitrogen and total phosphorus, they are efficient at retaining pulses of nitrates from upstream farms[30]. Established restored wetlands appear to be efficient at both retention of phosphorus (P) and removal of nitrogen (N). A study of four created/restored wetlands in Denmark showed that they retained 0.13-10 kg P ha^{-1} $year^{-1}$ and removed 52-337 kg N ha^{-1} $year^{-1}$ [31].

Disease/Pest Control—*Moderate evidence:-* As wetlands increase the abundance and density of migratory waterfowl, there may be increased risk of the import of avian influenza (H5N1 strains or similar) into the UK. This risk is most prevalent where the 24 migratory bird species most likely to carry the virus and high densities of poultry overlap[32]. Created wetlands can however remove microbial contaminants, such as *E. coli*, with efficiencies greater that 50%[33].

REFERENCES

1. Acreman, M.C., Harding, R.J., Lloyd, C., McNamara, N.P., Mountford, J.O., Mould, D.J., Purse, B.V., Heard, M.S., Stratford, C.J., Dury, S.J., 2011. Trade-off in ecosystem services of the Somerset Levels and Moors wetlands, Hydrological Sciences Journal-Journal Des Sciences Hydrologiques 56, 1543-1565. doi: 10.1080/02626667.2011.629783.
2. Connor, K.J., Gabor, S., 2006. Breeding waterbird wetland habitat availability and response to water-level management in Saint John River floodplain wetlands, New Brunswick, Hydrobiologia 567, 169-181. doi: 10.1007/s10750-006-0051-1.
3. Cordell, J.R., Toft, J.D., Gray, A., Ruggerone, G.T., Cooksey, M., 2011. Functions of restored wetlands for juvenile salmon in an industrialized estuary, Ecological Engineering 37, 343-353. doi: 10.1016/j.ecoleng.2010.11.028.
4. Bullock, A., Acreman, M., 2003. The role of wetlands in the hydrological cycle, Hydrology and Earth System Sciences 7, 358-389.
5. Wiseman, I., Rutt, G., Edwards, P., 2004. Constructed wetlands for minewater treatment: Environmental benefits and ecological recovery, Water and Environment Journal 18, 133-138. doi: 10.1111/j.1747-6593.2004.tb00514.x.
6. VanReesSiewert, K., Dinsmore, J., 1996. Influence of wetland age on bird use of restored wetlands in Iowa, Wetlands 16, 577-582.
7. Stevens, C., Gabor, T., Diamond, A., 2003. Use of restored small wetlands by breeding waterfowl in Prince Edward Island, Canada, Restoration Ecology 11, 3-12. doi: 10.1046/j.1526-100X.2003.00107.x.
8. Davies, B.R., Biggs, J., Williams, P.J., Lee, J.T., Thompson, S., 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, 7-17. doi: 10.1007/s10750-007-9227-6.
9. Smart, J., Amar, A., O'Brien, M., Grice, P., Smith, K., 2008. Changing land management of lowland wet grasslands of the UK: impacts on snipe abundance and habitat quality, Animal Conservation 11, 339-351. doi: 10.1111/j.1469-1795.2008.00189.x.
10. Armitage, A.R., Jensen, S.M., Yoon, J.E., Ambrose, R.F., 2007. Wintering shorebird assemblages and behavior in restored tidal wetlands in southern California, Restoration Ecology 15, 139-148. doi: 10.1111/j.1526-100X.2006.00198.x.
11. Ratti, J., Rocklage, A., Giudice, J., Garton, E., Golner, D., 2001. Comparison of avian communities on restored and natural wetlands in North and South Dakota, Journal of Wildlife Management 65, 676-684. doi: 10.2307/3803019.
12. Spieles, D., 2005. Vegetation development in created, restored, and enhanced mitigation wetland banks of the United States, Wetlands 25, 51-63. doi: 10.1672/0277-5212(2005)025[0051:VDICRA]2.0.CO;2.
13. Oughton, Elizabeth et al. 2009. Angling in the Rural Environment: Social, Economic, Ecological and Geomorphological Interactions. Full Research Report, ESRC End of Award Report, RES-227-25-0002. Swindon: ESRC
14. Rees, S., 1997. The historical and cultural importance of ponds and small lakes in Wales, UK, Aquatic Conservation-Marine and Freshwater Ecosystems 7, 133-139. doi: 10.1002/(SICI)1099-0755(199706)7:2<133::AID-AQC225>3.3.CO;2-5.
15. Waddington, J.M., Strack, M., Greenwood, M.J., 2010. Toward restoring the net carbon sink function of degraded peatlands: Short-term response in CO_2 exchange to ecosystem-scale restoration, Journal of Geophysical Research-Biogeosciences 115, G01008. doi: 10.1029/2009JG001090.

REFERENCES

16. Hahn-Scheofl, M., Zak, D., Minke, M., Gelbrecht, J., Augustin, J., Freibauer, A., 2011. Organic sediment formed during inundation of a degraded fen grassland emits large fluxes of CH_4 and CO_2, Biogeosciences 8, 1539-1550. doi: 10.5194/bg-8-1539-2011.
17. Augustin, J., Merbach, W., Rogasik, J., 1998. Factors influencing nitrous oxide and methane emissions from minerotrophic fens in northeast Germany, Biological Fertility and Soils 28, 1-4. doi: 10.1007/s003740050455.
18. Van den Pol-Van Dasselaar, A., Van Beusichem, M., Oenema, O., 1999. Determinants of spatial variability of methane emissions from wet grasslands on peat soil, Biogeochemistry 44, 221-237. doi: 10.1023/A:1006009830660.
19. Van den Pol-Van Dasselaar, A., Van Beusichem, M., Oenema, O., 1999. Methane emissions from wet grasslands on peat soil in a nature preserve, Biogeochemistry 44, 205-220. doi: 10.1023/A:1006061814731.
20. Schrier-Uijl, A.P., Kroon, P.S., Leffelaar, P.A., van Huissteden, J.C., Berendse, F., Veenendaal, E.M., 2010. Methane emissions in two drained peat agro-ecosystems with high and low agricultural intensity, Plant Soil 329, 509-520. doi: 10.1007/s11104-009-0180-1.
21. Juottonen, H., Hynninen, A., Nieminen, M., Tuomivirta, T.T., Tuittila, E., Nousiainen, H., Kell, D.K., Yrjala, K., Tervahauta, A., Fritze, H., 2012. Methane-Cycling Microbial Communities and Methane Emission in Natural and Restored Peatlands, Applied Environmental Microbiology 78, 6386-6389. doi: 10.1128/AEM.00261-12.
22. Ballantine, K., Schneider, R., Groffman, P., Lehmann, J., 2012. Soil Properties and Vegetative Development in Four Restored Freshwater Depressional Wetlands, Soil Science Society of America J. 76, 1482-1495. doi: 10.2136/sssaj2011.0362.
23. Cierjacks, A., Kleinschmit, B., Babinsky, M., Kleinschroth, F., Markert, A., Menzel, M., Ziechmann, U., Schiller, T., Graf, M., Lang, F., 2010. Carbon stocks of soil and vegetation on Danubian floodplains, Journal of Plant Nutrition and Soil Science 173, 644-653. doi: 10.1002/jpln.200900209.
24. Shultz, S., Leitch, J., 2003. The feasibility of restoring previously drained wetlands to reduce flood damage, Journal of Soil and Water Conservation 58, 21-29.
25. Cameron, K., Madramootoo, C., Crolla, A., Kinsley, C., 2003. Pollutant removal from municipal sewage lagoon effluents with a free-surface wetland, Water Research 37, 2803-2812. doi: 10.1016/S0043-1354(03)00135-0.
26. Jordan, T., Whigham, D., Hofmockel, K., Pittek, M., 2003. Nutrient and sediment removal by a restored wetland receiving agricultural runoff, Journal of Environmental Quality 32, 1534-1547.
27. Wiseman, I., Edwards, P., 2004. Constructed wetlands for minewater treatment: Performance and sustainability, Water and Environment Journal 18, 127-132. doi: 10.1111/j.1747-6593.2004.tb00513.x.
28. Ardon, M., Montanari, S., Morse, J.L., Doyle, M.W., Bernhardt, E.S., 2010. Phosphorus export from a restored wetland ecosystem in response to natural and experimental hydrologic fluctuations, Journal of Geophysical Research-Biogeosciences 115, G04031. doi: 10.1029/2009JG001169.
29. Zak, D., Wagner, C., Payer, B., Augustin, J., Gelbrecht, J., 2010. Phosphorus mobilization in rewetted fens: the effect of altered peat properties and implications for their restoration, Ecological Applications 20, 1336-1349. doi: 10.1890/08-2053.1.
30. Ardon, M., Morse, J.L., Doyle, M.W., Bernhardt, E.S., 2010. The Water Quality Consequences of Restoring Wetland Hydrology to a Large Agricultural Watershed in the Southeastern Coastal Plain, Ecosystems 13, 1060-1078. doi: 10.1007/s10021-010-9374-x.

REFERENCES

31. Hoffmann, C.C., Kronvang, B., Audet, J., 2011. Evaluation of nutrient retention in four restored Danish riparian wetlands, Hydrobiologia 674, 5-24. doi: 10.1007/s10750-011-0734-0.

32. Snow, L.C., Newson, S.E., Musgrove, A.J., Cranswick, P.A., Crick, H.Q.P., Wilesmith, J.W., 2007. Risk-based surveillance for H5N1 avian influenza virus in wild birds in Great Britain, Veterinary Record 161, 775-781.

33. O'Geen, A.T., Budd, R., Gan, J., Maynard, J.J., Parikh, S.J., Dahlgren, R.A., 2010. Mitigating non point source pollution in agriculture with constructed and restored wetlands, Advances in Agronomy, Vol 108 108, 1-76. doi: 10.1016/S0065-2113(10)08001-6.