SOCIETAL BENEFITS OF LARGE-SCALE RIVER AND WETLAND RESTORATION

About WWF

WWF is one of the world's largest and most experienced independent conservation organisations, with over five million supporters and a global network active in more than 100 countries. WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature by conserving the world's biological diversity, ensuring the sustainable use of renewable natural resources, and promoting the reduction of pollution and wasteful consumption.

Disclaimer

This report is based on a technical paper prepared by Badu Advisory Pty and Fluvial Systems for WWF-UK. The material in it reflects the best judgement of Badu Advisory Pty, Fluvial Systems and WWF-UK in light of the information available at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, is the responsibility of such third parties. Badu Advisory Pty, Fluvial Systems and WWF-UK accept no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions, based on this report. By making any designation of or reference to a particular territory or geographic area, or by using the term 'country' in this document, Badu Advisory Pty, Fluvial Systems and WWF-UK do not intend to make any judgements as to the legal or other status of any territory or area.

Citation

Speed, R., Gippel, C., Vollmer, D. and Tickner, D. (2026) Societal benefits of large-scale river and wetland restoration, WWF-UK, Woking, UK.

Front cover: © WWF-Pacific / Tom Vierus

© Karine Aigner / WWF-US

Badu Advisory Pty Ltd
ABN 17613 863 602
PO Box 2051
Keperra, QLD, 4054
AUSTRALIA

Email: info@baduadvisory.com

Web: www.baduadvisory.com

This report has been prepared in accordance with the scope of services described in the agreement between Badu Advisory and the client. The proposal has been prepared solely for use by the client and Badu Advisory accepts no responsibility for its use by other parties.

Executive Summary

Overview

This report synthesises global evidence showing that large-scale river and wetland restoration delivers measurable economic, environmental and social gains, directly advancing the Freshwater Challenge and the broader restoration agenda.

This report has been prepared for policy makers, planners, financial institutions and others responsible for decisions related to the protection and restoration of freshwater ecosystems. It was prepared using a modified version of the 'quick scoping review' methodology, drawing on published studies and grey literature to inform a high-level assessment of the benefits of freshwater restoration at the global level. The report compiles evidence for societal benefits of restoration against the key types of benefits provided by freshwater ecosystems.

Findings

Wetland ecosystems deliver over US $36.4 trillion in annual ecosystem service value, yet widespread degradation now jeopardises that return. Large-scale river and wetland restoration offers proven pathways to recover biodiversity and safeguard water and livelihood security.

Global evidence shows that large-scale freshwater restoration can deliver wide-ranging ecological and hydrological benefits, provided that the measures adopted are appropriate to the problem and the local context. Interventions such as river re-meandering, floodplain reconnection, wetland rewetting, and dam removal have restored biodiversity, improved water security, and enhanced cultural and livelihood values. Many restoration initiatives present as cost-effective complements (or alternatives) to grey infrastructure, particularly for flood mitigation and water treatment, while providing co-benefits that engineered approaches cannot.

Freshwater restoration provides multiple benefits to society. Hydrologically, it can increase water supply through greater infiltration and baseflows, increasing groundwater recharge and the reliability of flows during the dry season. This can increase water availability for dependent communities, particularly during dry periods. Restored wetlands and riparian zones filter sediments and nutrient pollution, lowering water treatment costs and health risks. Reconnected floodplains attenuate flood peaks, often reducing damage more effectively than traditional control measures. Climate benefits are also evident: peatland rewetting and wetland restoration can curb greenhouse gas emissions by turning degraded carbon sources into net carbon sinks, supporting both mitigation and adaptation goals. Restoration also generates provisioning and cultural benefits, such as improved fisheries, expanded recreation and tourism, and renewed cultural connections to rivers.

Ecological outcomes include recovery of fish, waterbirds, and specialist wetland species driven by revitalised flow regimes and habitat complexity. In addition, freshwater ecosystem restoration enhances climate resilience by reinstating natural processes that buffer societies against the increasing frequency and intensity of floods, droughts, and other climate-driven extremes. Overall, freshwater restoration offers a powerful, evidence-based pathway to build resilience and deliver diverse societal benefits.

The societal benefits of river and wetland restoration are summarised in Table 1.

Table 1. Benefits attributable to freshwater restoration. Supporting evidence for each statement of finding (F1-F19) is set out in detail in section 3 and in Appendices B-H

Water Supply
Potential benefits from freshwater restoration

F1. **Increased water yield and more reliable baseflows**: Freshwater ecosystem restoration can augment water yields for human use. Increased infiltration into soils and aquifers because of restoration enhances soil moisture and improves baseflows.

F2. **Enhanced groundwater recharge**: By increasing soil infiltration, freshwater ecosystem restoration increases aquifer recharge.

Examples

- In South Africa, removing invasive riparian vegetation increased annual water yield by 34.4 million m³, about 42% of the output of a new dam and for less than 20% of the cost per m³
- In Nepal catchment restoration (including reforestation and recharge ponds) improved the average yield of surface and groundwater sources by 75%
- In the Upper Midwest, USA, restoration of grassland and wetlands increased baseflow by 40%
- In Ethiopia, catchment restoration increased water tables by 10-15 meters.

Pollution reduction
Potential benefits from freshwater restoration

F3. **Improved water quality**: Wetlands and riparian buffers trap sediments, take up excess nutrient pollution, and break down contaminants before water reaches rivers or aquifers, resulting in improvements in key water quality parameters.

F4. **Reduced water treatment costs**: Restoration can significantly reduce the need for expensive water treatment infrastructure and ongoing water treatment costs.

F5. **Improved drinking water and public health outcomes**: Restoration can reduce turbidity, pathogens, and nutrient runoff, lowering the risk of contaminated drinking water.

Examples

- Conservation and restoration of rivers and their catchments allowed New York city to avoid construction of an $8-10 billion filtration plant as well as avoiding annual treatment costs of $365 million/year (achieved through measuring costing ~$100 million/year)
- Fencing streams to exclude cattle and revegetating riparian corridors can reduce microbial contamination from *Cryptosporidium* by 93%
- Restoration measures in the Great Barrier Reef catchments, including improved farming practices, have stopped 140,000 tonnes of fine sediment and 550 tonnes of dissolved inorganic nitrogen from entering the Reef lagoon.

Flood risk reduction

Potential benefits from freshwater restoration

F6. **Attenuation of flood peaks and cost-effective flood management**: Reconnecting rivers to floodplains and restoring wetlands markedly reduces flood surges. Reducing flood risks via nature-based solutions is often more cost-efficient than hard infrastructure.

F7. **Reduced flood damages**: By absorbing excess water and reducing flood peaks, restored floodplains and wetlands significantly reduce the damage caused by floods.

Examples

- Work in the Yangtze basin has resulted in an additional 29,700 km^2 of restored floodplains with a floodwater retention capacity of 8 billion m^3
- Restoring lost floodplains in the Upper Mississippi Basin could store ~48 billion m^3 of floodwater and avoid an estimated $16 billion in flood damages
- $1 invested in floodplain restoration today can avoid about $5 in future flood losses.

Carbon sequestration

Potential benefits from freshwater restoration

F8. **Rewetting of peatlands is a favoured wetland restoration measure to achieve carbon storage and GHG benefits.** This is because: (i) they have a high natural carbon storage capacity, (ii) large areas of peatland have long been subjected to draining, becoming ongoing sources of carbon to the atmosphere, and (iii) rewetting to increase carbon storage capacity and prevent further carbon loss is relatively straightforward.

F9. **Emissions from degraded wetlands could be substantially reduced through restoration.** Restoration across 355–484 million hectares of wetlands could sequester 3—9% of current global carbon emissions.

Examples

- Global-scale reviews and modelling show that wetland (including peatland) restoration can prevent up to hundreds of petagrams of CO_2 emissions by 2100, sequester over 1 Pg CO_2 annually, and cut net warming potential of wetlands by more than 60%.
- In Israel and China rewetting of drained wetlands reduced CO_2 losses and increased soil organic matter.
- Numerous rewetting projects in Europe show consistent reductions in CO_2 emissions and avoided losses, though methane emissions often rise temporarily. Benefits grow over decades, with rewetted peatlands shifting towards carbon sinks.
- Field studies in the United States and Canada demonstrate that raising water tables in peatlands and floodplains cut CO_2 losses by up to 90%, with restored sites showing markedly lower net GHG fluxes than drained controls.

Food security

Potential benefits from freshwater restoration

F10.   **Restoration through community co-management and establishing fish refuges rapidly rebuilds fish stocks and increases fisher incomes.** This has knock-on benefits, including raised fish consumption and improved food security among poorer households.

F11.   **Reconnecting rivers (dam removals and fish passage) restores migratory fish runs that underpin regional fisheries.** Removal of dams and establishing fish passages has been shown to improve migration, spawning conditions, and overall fish numbers.

F12.   **Restored freshwater wetlands and reconnected floodplains can deliver quantified food provisioning (as well as fibre and energy) that buffers household food security.** Restoration has been shown in increase populations of fish species and waterbirds, as well as the extent of wetland vegetation, that are key food sources for local communities and/or contribute to household income.

Examples

- In Malawi, community-managed fish refuges increased observed fish species richness by approximately 24%.
- In Bangladesh's Hail Haor wildlife sanctuary, managed fish refuges and seasonal closures of the wetland increased fish catch by about 88% and raised fish consumption among poorer households.
- In Nepal's Lake Rupa, cooperative action increased annual fish production from 18.5 tonnes to around 70 tonnes.
- On Maine's Penobscot River in the United States, dam removals and fish-passage upgrades have enabled annual returns of more than five million river herring, revitalising river-dependent fisheries.
- On the Brazilian Amazonian floodplains of the Juruá and Purus systems, protected lakes hold substantially larger arapaima (a key fish) populations than open-access waters, and co-managed lakes show higher catches and fisher revenues.

Cultural and social benefits

Potential benefits from freshwater restoration

F13.   **Increased outdoor recreation and tourism**: Restoring rivers has been shown to increase recreation opportunities and usage, including more people swimming, paddling, boating, fishing, and viewing wildlife, as well as bringing economic benefits to communities and local businesses.

F14.   **Strengthened cultural and spiritual connections**: River restoration, such as improving flows or removing barriers, can restore access to culturally important species and sites.

F15.   **Improved aesthetic quality and community well-being**: Restoration can transform waterways into attractive public spaces, enhancing recreational spaces, improving human mental and physical wellbeing, improving community pride, and reconnecting people with their local environment.

Examples

- Restoration of an urban park in Singapore saw annual visitation to the park double from ~3 million to 6 million
- Decommissioning a dam and establishing a wetland reserve in Victoria, Australia led to double the numbers of visitors for walking, cycling birdwatching, and canoeing
- Removal of dams on the Elwha River in Washington, USA, reopened over 110 km of salmon habitat, allowing the Lower Elwha Klallam Tribe to renew salmon fishing traditions and spiritual ceremonies that had been suppressed for a century
- A USD 10 million investment in restoring Muskegon Lake resulted in total local economic benefits of ≈ USD 60 million through increased tourism and raised property values.

Biodiversity and supporting services

Potential benefits from freshwater restoration

F16. **Hydrological reconnection and managed water regimes drive multi-taxon recovery.** Where floodplains are reconnected and water levels managed to mimic seasonal variation, biodiversity responses are strong and consistent.

F17. **Removing barriers restores native fish assemblages and aquatic communities.** Connectivity restoration has yielded rapid fish responses in a range of different settings.

F18. **Large-scale river and floodplain reconnection delivers ecosystem-wide gains.** Benefits include increases in floodplain wetland and floodplain forest extent and condition as well as increases in fish assemblage and bird densities.

F19. **Targeted wetland restoration enables recovery of specialist communities.** Measures including rewetting, nutrient-load reduction, restoration of groundwater inputs, re-naturalising channel morphology and habitat complexity, and removing invasive predators have returned characteristic plant communities, improved habitat quality, and led to significant improvements in fish, macroinvertebrate and macrophyte indices.

Examples

- Partial reflooding of the Waza–Logone floodplain (Cameroon) produced large increases in waterbirds (species-level gains of +135% to +744%) and expanded typical annual flood extent by about 1,000–1,500 km²
- Hydrological restoration at Ichkeul National Park (Tunisia) has supported wintering populations in the order of 100,000–200,000 birds in typical years, and up to 300,000 in some years.
- At East Dongting Lake (middle Yangtze River, China), floodplain restoration through changes to dykes yielded higher wintering waterbird richness, density and diversity.
- In Australia managed environmental flows to large floodplain wetland systems supported very large colonial waterbird breeding events.

Contribution to international environmental agreements

The review found there is substantial evidence that restoration of freshwater ecosystems has the potential to contribute towards the goals of a wide range of international environmental agreements (Table 2).

Table 2. Contribution of freshwater restoration towards international environmental agreements

Agreement	Relevant goal/target	Restoration benefit
Convention on Biological Diversity (CBD)	2030 Global Biodiversity Framework – Restore 30% of degraded inland water ecosystems	Biodiversity & supporting ecosystem services
	Ensure sustainable use of biodiversity (maintain ecosystem services)	Water supply, pollution reduction & flood risk reduction
UN Framework Convention on Climate Change (UNFCCC)	Paris Agreement – Mitigation (reduce GHG emissions)	Carbon storage and GHG fluxes
	Paris Agreement – Adaptation (enhance climate resilience)	Flood risk reduction
		Water supply
UN Convention to Combat Desertification (UNCCD)	Combat desertification and drought (Land Degradation Neutrality)	Water supply
Sustainable Development Goal (SDG) 6	*Target 6.3:* Improve water quality *Target 6.4:* Ensure sustainable water withdrawals *Target 6.6*: Protect and restore water-related ecosystems	Water supply & pollution reduction
SDG 15	*Target 15.1*: Restore inland freshwater ecosystems & services	Biodiversity & supporting ecosystem services
SDG 2	Zero Hunger – improve food security and nutrition	Food security
SDG 13	Climate Action – strengthen resilience to climate impacts	Water supply & flood risk reduction
Sendai Framework for Disaster Risk Reduction	2030 goal to substantially reduce disaster losses	Flood risk reduction
	2030 goal to substantially reduce disaster losses	Water supply
Ramsar Convention on Wetlands	Wise use of wetlands – maintain ecological character	Biodiversity and supporting ecosystem services

Trade-offs

Economic assessments consistently find that freshwater restoration delivers a net economic benefit. However, the benefits can come with trade-offs between competing objectives and unintended negative impacts with implications for social justice and equity. For example, restoring natural floodplains can improve carbon sequestration and reduce flood risks, but often requires the loss of farmland. Restoration can impose uneven costs on certain communities and economic sectors. Affected groups may include local residents who are displaced, resource users whose activities are curtailed, or industries facing new restrictions. Restoration can also involve balancing short-term costs for long-term gains. For example, re-wetting dried peatlands can cause a short-term spike in methane emissions but result in a huge reduction in carbon dioxide emissions and net climate benefit over the long-term.

8

The review identified several strategies for managing trade-offs associated with freshwater restoration in order to ensure just and equitable outcomes. These include:

- Early and effective stakeholder engagement
- Balancing the long-range vision with short-term support measures
- Understanding the timing of costs and benefits
- Recognizing that different time horizons matter to different stakeholders
- Adopting a multi-benefit focus.

Acknowledgements

Shortened forms

Short form	Full form
BMP	Best Management Practices
CBD	Convention on Biological Diversity
CBM	Community-Based Management
CH_4	Methane
CMA	Catchment Management Authority (Australia)
CNRS	Center for Natural Resource Studies (Bangladesh)
CO_2	Carbon Dioxide
CO_2-eq	Carbon dioxide equivalent
DCCEEW	Department of Climate Change, Energy, the Environment and Water (Australia)
DEFRA	Department for Environment, Food & Rural Affairs (UK)
DFFE	Department of Forestry, Fisheries and the Environment (South Africa)
E. coli	*Escherichia coli* (indicator bacteria)
EEA	European Environment Agency
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gas
GWP / GWPs	Global Warming Potential(s)
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
N_2O	Nitrous Oxide
NbS	Nature-based Solutions
PICO	Population, Intervention, Comparator, Outcome
PUB	Public Utilities Board (Singapore)
QSR	Quick Scoping Review
SDG	Sustainable Development Goal
SOC	Soil organic carbon

SOM	Soil Organic Matter
TNC	The Nature Conservancy
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNDRR	United Nations Office for Disaster Risk Reduction
UNW	United Nations Water
USACE	U.S. Army Corps of Engineers
WEF	World Economic Forum
WHO	World Health Organization
WMO	World Meteorological Organization
WWF	World Wide Fund for Nature

1   Introduction

1.1   Purpose and intended audience of this report

Healthy rivers and wetlands regulate floods and droughts, recharge groundwater, support fisheries, provide drinking water, and support food and fibre production. They also generate energy, store carbon, filter, dilute and degrade pollutants, and provide cultural values including recreation, ecotourism, religiosity, and spirituality, making them critical natural solutions for climate adaptation and sustainable development (Carpenter et al., 2011; Petsch et al., 2023).

However, human pressures over the past century have severely degraded freshwater habitats worldwide, undermining their capacity to provide these critical services. For example, around 21% of global wetland area has been lost since 1700 (Fluet-Chouinard et al., 2023). In addition, many rivers and wetlands have been severely degraded, with the main drivers of change being climate change, hydrologic flow modification, fragmentation, land-use change, chemical inputs, aquatic invasive species, and over-harvesting (Carpenter et al., 2011).

The purpose of this report is to synthesize existing evidence on the societal benefits of large-scale river and wetland restoration, in support of the Freshwater Challenge (see **Box 1**) and the broader global restoration agenda. The report does not define 'large-scale' in terms of a minimum geographic extent or area. Rather, the report has prioritised consideration of restoration interventions at the catchment, regional or landscape scale, and has sort to avoid where possible small, isolated projects.

The report is intended to provide a resource for policy makers, planners, financial institutions and others responsible for decisions related to the protection and restoration of freshwater ecosystems. This includes those involved in sustainable water management, environmental restoration, sustainable development and climate finance. In collating the evidence of the benefits of freshwater restoration, the report presents the value proposition for investing in freshwater restoration.

The report has been prepared based on rapid review of the available evidence, based on a modified version of a 'quick scoping review' (Collins et al, 2015). It has involved a review of published studies and grey literature to inform a high-level assessment of the benefits of freshwater restoration at the global level, informed by case-studies and evidence collected at the national and regional scale. The report assesses the evidence of benefits against the key types of ecosystem services provided by freshwater ecosystems. While the report considers the socio-economic benefits and trade-offs associated with freshwater restoration, it does not undertake a detailed economic analysis or seek to quantify the economic costs and benefits associated with freshwater ecosystems and the services they provide.

The report consists of the following:

- A brief introduction to freshwater ecosystems, their importance ecologically and to society, major threats, and the concept of ecosystem restoration. This section also discusses the potential for freshwater restoration to contribute towards various international environmental agreements (section 1, this section).
- A summary of the methodology used in developing the report (section 2).
- A synthesis of the evidence of the benefits of freshwater ecosystem restoration, mapped against key categories of benefit – water supply, pollution reduction, flood risk reduction etc (section 3). This section sets out, for each category of benefit:
    - The role of freshwater ecosystems in providing the benefit, and

    o Findings related to the evidence of the impact of restoration measures on the extent
       of the benefit. Findings are listed (F1, F2, F3 etc) and cross-referenced throughout
       the report. These findings are supported by the evidence tables (Appendix B-H).
- A discussion of the key trade-offs involved in freshwater ecosystem restoration, including
  disbenefits associated with restoration and trade-offs between different benefits (section 4).
- Conclusions and recommendations from the review (section 5).
- The Quick Scoping Review methodology (Appendix A).
- Detailed evidence tables for each of the categories of benefit (Appendix B-H).

Box 1: The Freshwater Challenge

Launched in 2023 at the UN Water Conference, the Freshwater Challenge is an initiative under the auspices of the UN Decade of Ecosystem Restoration that aims to respond to the challenge of degraded and declining freshwater ecosystems. The Freshwater Challenge aims to restore 300,000 km of degraded rivers and 350 million hectares of degraded wetlands by 2030 as well as securing the protection of freshwater ecosystems important for biodiversity and ecosystem services.

The Freshwater Challenge is a country-led initiative currently supported by more than 50 countries and the European Union[1] that emphasizes integrating freshwater restoration into national policies and plans across sectors such as agriculture, energy, and urban development. By mobilizing resources and expertise, the initiative aims to enhance water, food, and energy security, mitigate climate change impacts, and foster resilient ecosystems. The Freshwater Challenge promotes setting quantifiable targets and implementing actions that align with global commitments like the Sustainable Development Goals (SDGs) and the Global Biodiversity Framework.

Source: Freshwater Challenge (2023), https://www.freshwaterchallenge.org/

1.2   Freshwater ecosystems and why they matter

For this report, freshwater ecosystems are defined in terms of aquatic ecosystems that are inland and not saline. This includes rivers, lakes, pools, springs, swamps, peatlands, headwaters to large rivers, and groundwater-dependent ecosystems. The report does not directly consider coastal ecosystems that are tidally influenced, although estuaries, most mangroves and other brackish ecosystems are dependent on freshwater inputs. Consequently, this report does not consider restoration of such systems, but they can be relevant to decisions related to the restoration of upstream freshwater systems. Similarly, freshwater ecosystems are influenced by their catchments and restoring the health of a catchment can be fundamental to restoring freshwater systems downstream.

Under some definitions, notably that adopted by the Ramsar Convention, wetlands are defined to include rivers (Convention on Wetlands, 1971). For the purposes of this report, we distinguish between wetlands and rivers, adopting the approach taken by a range of organisations (Australian National Aquatic Ecosystem Classification Framework; US Fish & Wildlife Service (Cowardin et al., 1979); IPCC, 2014). Under this approach, a wetland is defined as an area of land that is saturated, flooded or inundated with water, either permanently or temporarily, and supports vegetation and

---

[1] As at July 2025

ecological communities adapted to wet conditions. This includes peatlands, marshes, swamps, mangroves, and floodplains. The distinction is however somewhat arbitrary, and there is, inevitably, overlap between 'rivers' and 'wetlands'.

Freshwater ecosystems provide a range of critical benefits to people and the planet, including:

- **Water supply**: Freshwater ecosystems are the source of most water used for drinking, hygiene, and agriculture, with rivers, lakes, and aquifers supplying billions of people (UNEP, 2021).
- **Food provisioning**: Inland fisheries provide food for billions and livelihoods for millions, particularly in developing regions (Lynch et al, 2020). Many staple crops depend on large supplies of freshwater to produce the quantities of food required to sustain the global population (Lynch et al., 2023a; 2023b).
- **Carbon sequestration**: Freshwater ecosystems moderate climate by storing carbon. Peatlands and other wetlands act as massive carbon sinks, holding an estimated 20% of global soil carbon (Sapir et al., 2025).
- **Flood regulation and pollution reduction**: Healthy floodplains and vegetated riverbanks hold back floodwaters and reduce erosion, while aquatic plants and microbes filter pollutants from water (Ponting et al., 2021). These natural functions maintain water quality and protect communities.
- **Recreation and cultural value**. Lakes and rivers offer recreation opportunities (swimming, boating, fishing, ecotourism), enhancing quality of life, improving human health and wellbeing, and supporting local economies (Sterner et al., 2020; Grizetti et al, 2019; Lynch, 2023a; 2023b). Moreover, nearly every culture has traditions or spiritual beliefs tied to rivers, lakes, or the species within them (Knoll et al, 2019; Rodrigues, 2015).
- **Biodiversity support and ecological health**. Freshwater ecosystems are hotspots of biodiversity, which underpins all the services described above. While freshwater habitats cover between 1 and 5% of Earth's surface, they harbour roughly 10% of all known animal species, including an outsize share of the world's fish species (Strayer and Dudgeon, 2010). This biodiversity drives ecosystem functions such as nutrient cycling and water purification as well as providing a critical reservoir of genetic resources.

1.3   Global trends in freshwater ecosystem health

Freshwater ecosystems deliver an estimated US$36.4 trillion in annual ecosystem-service value (Convention on Wetlands, 2025). The economic use value of water is estimated at approximately $58 trillion, equivalent to 60% of global GDP in 2021 (WWF, 2023). Despite this, widespread degradation now jeopardises that return.

Freshwater biodiversity has undergone steep global declines in recent decades (Albert et al., 2021). Populations of freshwater vertebrates have declined by 85% since 1970, the largest drop of any biome. This includes a drop in migratory freshwater fish populations of over 80% (WWF, 2024). Habitat extent has declined in parallel. Wetlands have shrunk rapidly due to drainage and land conversion. Around 20% of the world's wetlands have been lost since 1700 (Fluet-Chouinard et al., 2023), with wetlands currently disappearing three times faster than forests (Ramsar Convention on Wetlands, 2018). Likewise, river systems have been heavily altered. Only about one-third of the world's long rivers remain free-flowing from source to sea due to dams and water withdrawals (Grill et al, 2019; WWF, 2020).

Freshwater species are increasing becoming threatened with extinction. A recent global assessment by the IUCN found that roughly one in four freshwater animal species, including fish and many freshwater-dependent reptiles and amphibians, are at risk of extinction (Sayer et al, 2025).

The decline in freshwater ecosystem health is driven by multiple human-induced pressures, including:

- **Habitat loss and flow alteration**: Land-use change and hydrological alteration are the biggest drivers of freshwater ecosystem decline, driven by the conversion of wetlands and floodplains for agriculture and urban development and the damming and diversion of rivers (UNEP & UNW, 2024). The resultant changes in water flow and sediment supply degrade habitats and impede species migrations.

- **Pollution and water quality degradation**: Freshwater health is severely impacted by pollution from agricultural runoff, sewage, industrial effluents, and mining. Excess nutrients from human waste and fertilizer runoff cause eutrophication in lakes and estuaries. Toxic contaminants and plastics also accumulate in waterways. Pollution affects over 50% of threatened freshwater species studied (Sayer et al, 2025) and undermines human uses of water.

- **Over-exploitation of resources**: Extraction of freshwater resources for irrigation, industry, and towns is often unsustainable. Overuse has led to some rivers (such as the Colorado and Indus) running dry seasonally, and the desiccation of lakes (such as the Aral Sea) and wetlands (UNEP & UNW, 2024). In addition, many freshwater species are overharvested (Carrizo et al., 2017).

- **Invasive species and diseases**: Non-native species in freshwater systems, including fish, invasive plants, and disease pathogens, have caused extinctions and habitat changes and are a significant threat in many lakes and rivers. Globally, around 28% of freshwater species are threatened by invasive species or diseases (Sayer et al., 2025).

- **Climate change**: Changes in precipitation and melting of glaciers are altering river flows, intensifying droughts in some regions and flood risks in others. Warming temperatures alter freshwater habitats, for example, reducing oxygen levels and stressing temperature-sensitive species, and climate-driven sea-level rise can salinize coastal freshwater wetlands (UNEP & UNW, 2024).

These drivers often act in combination, resulting in a compounding impact on freshwater ecosystem health, evidenced by declines in key species and reduced ecosystem services.

1.4   What do we mean by restoration?

The global decline in biodiversity has driven renewed efforts at the conservation and restoration of ecosystems (Aronson et al., 2020). **Ecological conservation** is the protection and maintenance of ecosystems, natural habitats, and biodiversity in their existing state, typically with the aim of preventing degradation, species extinction and habitat loss (Fetene et al., 2012).

In contrast, **ecological restoration** (including freshwater restoration) is a complementary approach that involves repairing or restoring degraded or destroyed ecosystems. Conservation and restoration measures are however not wholly distinct from one another. For example, conservation can involve restoring some of the habitats to be protected. Similarly, effective restoration may require that the restored habitat or ecosystem be protected from further degradation.

Historically, 'ecological restoration' has focussed on returning ecosystems to their natural or pre-development state (National Research Council, 1992). However, more recent approaches have shifted away this idealised notion to a broader, more pragmatic and utilitarian approach to restoring and managing ecosystems (Speed et al., 2016b). Returning rivers and other freshwater systems to a pre-development condition is now physically or economically impractical or impossible in many settings and would place politically unacceptable constraints upon current and future human activities. Further, in the face of a changing climate, historic conditions are no longer an appropriate benchmark. As such, freshwater restoration now captures a broad range of measures aimed at improving ecosystem health and resilience, including to climate change, but that do not necessarily include the objective of returning the system to its natural state (Dufour & Piégay, 2009; Lynch et al., 2024).

Table 3. Typology of restoration measures. Source: Speed et al., 2016b

Element of river ecosystem	River restoration measure	Used in river restoration to:	Examples of different measures	
			Active restoration	Passive restoration
Catchment	Catchment management	Alter the water, sediment, and other matter that enters the river channel	Revegetation of the catchment. Rehabilitation of gullies/high-erosion zones. Land and water conservation	Land use planning/regulatory controls on land use, vegetation clearing. Promotion (compulsory or voluntary) of agricultural best management practice
Flow Regime	Flow modification	Change the volume, timing, frequency, and duration of flows	Buy back of water entitlements and actively managing the water for improved environmental outcomes. Removal/re-engineering of floodplain drainage	Mandating release of e-flows for hydropower/dam operators. Restrictions on abstraction of water by water users
	Stormwater management	Alter the flow pattern of water running off from urban areas, e.g. altering flood peak	Construction of ponds, wetlands, flood retention basins, or other flow regulators in urban areas. Removal/reduction of impervious surfaces in the urban catchment	Urban development and design requirements
	Dam removal/ retrofit	Improve flows and ecological outcomes, including improving the movement of sediment and fish	Removal of redundant dams or weirs. Retrofitting of fish passages to existing dams or weirs	Regulatory requirements on dam operators
	Floodplain reconnection	Reduce flood risk by increasing the capacity of the river system to store and release floodwaters. Allow for the movement biota, sediment, and other matter between the channel and floodplain. Increase assimilation of pollutants and groundwater recharge	Removal of levee banks. Construction of infrastructure (e.g. choke points) to increase frequency of flooding	Mandating release of e-flows for hydropower/dam operators. Restrictions on abstraction of water by water users
Habitat (riparian)	Riparian management	Alter the water, sediment, and other matter that enters the river channel; provide habitat; alter water temperature through shading; support migration along the river corridor	Revegetation of riparian zone. Removal of invasive plants	Exclusion of cattle and other invasive species. Regulatory restrictions on clearing of riparian vegetation
	Land acquisition	Acquire riparian lands to control land use and/or allow for restoration works	Purchase of land in sensitive/high-value areas	
Habitat (instream)	Instream habitat improvement	Promote or create habitat that supports biodiversity	Creation of habitat via introduction of logs/snags; planting of instream vegetation	Restrictions on mining and other extractive activities within the river channel
	Bank stabilization	Reduce erosion/slumping of bank material into the river	Strengthening/reshaping of river bank. Planting of vegetation directly on the river bank	Restrictions on activities on the river bank
	Channel reconfiguration	Altering the channel plan form or the longitudinal profile, thus increasing hydraulic diversity and habitat heterogeneity and decreasing channel slope	Daylighting (opening of pipes/removal of coverings). Re-meandering of river channel	
Water Quality	Water quality management	Protect or improve water quality, including chemical composition and particulate load	Construction or upgrade of wastewater facilities. Capture of urban litter and sediment. Mine remediation. Wetland restoration	Changes to dam release operations to manage water temperature. Regulatory requirements on management/ discharge of pollutants
Biodiversity	Instream species management	Protect or improve number/diversity of important species	Stocking/re-introduction of species	Controls on harvesting/removal of species. Establish conservation zones
Other	Aesthetics/ recreation/ education	Increase community value, such as by improving appearance, access, or knowledge	Creation of riparian parks, walkways, and river access points. Education facilities	

Freshwater restoration can involve changes to the physical, chemical, biological, and hydrological aspects of an ecosystem. This may involve reducing point source pollution (e.g. through improved wastewater treatment), reducing diffuse pollution (e.g. through cutting fertiliser use or improved agricultural management within the catchment), restoring ecologically important flows (e.g. through dam operation rules), removing barriers to movement along a watercourse (e.g. by removing dams or levees, or constructing fish ways), protecting or reintroducing biota, or reshaping the watercourse through direct interventions (Speed et al., 2016a, Speed et al., 2016b, Table 3). Importantly, to be effective, restoration measures need to be selected that respond to the problem of concern, and that are appropriate to the local context.

Freshwater restoration can occur at a local scale (such as revegetating the banks of a small stream), or at a basin or landscape scale, involving major changes to land use or water resources management. Importantly, evidence highlights the importance of adopting a strategic approach to restoration. This requires that decisions about the management and restoration of freshwater ecosystems be undertaken in a way that (Speed et al., 2016a):

- Is based on contemporary knowledge of ecosystems and the ecosystem services they provide
- Is based on the long-term needs for and objectives of human society related to freshwater ecosystem services
- Identifies the capacity of the freshwater ecosystem to provide the desired ecosystem services under different conditions, and
- Manages the impacts of human society on ecosystems and targets the primary threats to ecosystem health (Tickner et al., 2020 – see **Box 2**).

Box 2: Bending the Curve of Global Freshwater Biodiversity Loss: An Emergency Recovery Plan

In response to the accelerating loss of freshwater biodiversity, Tickner et al. (2020) propose an "Emergency Recovery Plan" that emphasizes restoration of freshwater ecosystems. The plan identifies six key actions to protect and revive rivers, lakes, and wetlands: accelerating the implementation of environmental flows, improving water quality, protecting and restoring critical habitats, managing exploitation of species and riverine aggregates, managing non-native species invasions, and safeguarding and restoring river connectivity. Protecting and restoring critical habitats, such as wetlands, floodplains, and free-flowing rivers, is highlighted as essential for biodiversity recovery. Likewise, reconnecting rivers by removing or redesigning dams and levees is prioritized to restore migratory pathways and natural flows. Improving water quality through better wastewater treatment, pollution control, and nature-based solutions is another pillar of the strategy. The Emergency Recovery Plan calls for embedding these restoration actions into global biodiversity and sustainable development agendas.

1.5   Policy opportunities

The extent of the loss of freshwater biodiversity and ecosystem degradation is daunting. However, the Freshwater Challenge, as well as broader efforts aimed at freshwater restoration, are being undertaken at a time of great opportunity.

The UN Decade on Ecosystem Restoration (2021–2030) is a global movement to scale up restoration to combat climate change and biodiversity loss. Freshwater ecosystems are a priority of the UN Decade, given their outsized contribution to human well-being and their dire state. In addition, the

new Global Biodiversity Framework, adopted in 2022 under the UN Convention on Biological Diversity (CBD), includes explicit area-based targets for restoration of degraded ecosystems by 2030, which countries are now translating into national plans (Steel et al., 2025). Likewise, momentum is building in climate policy to finance Nature-based Solutions (NbS), including river and wetland restoration, as cost-effective strategies for climate change mitigation and adaptation.

Indeed, the restoration of freshwater ecosystems has the potential to contribute towards the goals of a wide range of international environmental agreements (Table 4). Further, there is growing recognition across the private sector of the importance of maintaining ecosystem health to underpin healthy and prosperous economies (FAO Land & Water, 2015; WEF, 2023). This is supported by a growing pool of both private and public funds seeking opportunities to invest in improved ecological outcomes, including those related to carbon abatement.

Table 4. Contribution of freshwater restoration to the goals and objectives of international environmental agreements.

International agreement	Goals/objectives	How freshwater restoration may contribute
UN Convention on Biological Diversity (Kunming–Montreal Global Biodiversity Framework)	Conserve biodiversity and ensure its sustainable use. Sets targets for 2030 including to effectively conserve 30% of land, inland waters, and seas, and to restore at least 30% of degraded terrestrial and inland water ecosystems.	Revives habitats for freshwater species, supports biodiversity outcomes and improves ecosystem services (e.g. water purification, flood regulation).
UN Framework Convention on Climate Change (UNFCCC) and Paris Agreement	Prevent dangerous climate change by stabilizing greenhouse gas (GHG) concentrations in the atmosphere. Key objectives include reducing GHG emissions and adapting to unavoidable climate change effects.	Contributes to both mitigation and adaptation goals. Healthy wetlands and peatlands can store carbon (mitigation), while restored rivers and floodplains reduce flood risks and improve water supplies (adaptation).
UN Convention to Combat Desertification (UNCCD)	Combat desertification and land degradation and mitigate the effects of drought in dryland regions.	Can decrease excess surface runoff and increase infiltration, hence increasing groundwater recharge and water supply reliability.
UN Sustainable Development Goals (2030 Agenda)	SDG 6 (Clean Water and Sanitation) includes Target 6.3: Improve water quality Target 6.4: Ensure sustainable water withdrawals Target 6.6: Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes. SDG 15 (Life on Land) includes Target 15.1: Conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services.	Contributes to SDG 6 by improving water quality, quantity and ecosystem health and SDG 15 by restoring degraded inland waters and conserving biodiversity. Healthier wetlands also support food security and livelihoods (SDG 2 – Zero Hunger) and enhance climate resilience (SDG 13 – Climate Action).
Sendai Framework for	Aims to substantially reduce disaster risk and losses by 2030. Goal is "the	Reviving natural features like floodplains, wetlands, and

International agreement	Goals/objectives	How freshwater restoration may contribute
Disaster Risk Reduction (2015–2030)	substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries."	mangroves can mitigate flooding and buffer droughts, reducing the impact of water-related disasters on communities, which represent 90% of natural disasters globally (United Nations, Department of Economic and Social Affairs. (n.d.)).
Ramsar Convention on Wetlands	Conserve and wisely use wetlands through local, national and international actions. Ramsar's mission is to halt the worldwide loss of wetlands and ensure their ecological character is maintained.	Restoring a drained marsh or a polluted lake, for example, can revive biodiversity, improve water storage and quality, and re-establish the natural functions that wetlands provide.

2   Methods

2.1   Approach and framework

This report has been developed using a modified version of a quick scoping review (QSR) (Collins et al, 2015) as the basis for synthesising existing evidence on the societal benefits associated with large-scale river and wetland restoration.

The conceptual framework guiding the review is shown in Figure 1. The framework hypothesises that restoration leads to improved ecosystem states, enhanced ecosystem services, and subsequently, tangible societal benefits. Restoration interventions considered include reconnecting rivers with floodplains, rewetting peatlands, riparian reforestation, removal of barriers, pollution reduction, and the establishment of natural flow regimes. These actions may restore key ecological functions such as hydrological connectivity, water retention, carbon sequestration, and supporting biodiversity. Enhanced ecosystem services can translate into benefits including cleaner water, reduced flood risk, climate adaptation and mitigation, food and water security, and livelihood enhancement through fisheries and ecotourism.

Benefits might be felt at societal scale, but the degree to which individuals, households or groups of people are impacted (positively or negatively) will be influenced by non-ecosystem factors including the existence and operation of infrastructure and the decisions made by land and water management institutions. It's beyond the scope of this report to explore these issues in depth, but they will be important contextual considerations in implementing any restoration initiative.

Restoration intervention	Improved ecosystem state	Enhanced services	Societal benefits	Global targets
• Restoring flows • Reduced pollution • Reshaping watercourse • Reconnecting floodplains • Removal of barriers	• Improved flows & connectivity • Improved water quality • Biodiversity	• Water retention • Carbon sequestration • Biodiversity support	• Water supplies • Reduced flood risk • Climate adaption • Food security • Cultural and social	• CBD • UNFCCC • SDGs • Ramsar • UNCCD • Sendai Framework

Figure 1. Conceptual framework for freshwater ecosystem restoration. The examples listed are representative, not exhaustive.

2.2   Research questions

The primary research question guiding the QSR is: "**What is the evidence of societal benefits and trade-offs associated with large-scale river and wetland restoration?**". This was explored through the Population, Intervention, Comparator, Outcome (PICO) framework:

- Population (P): The review focused explicitly on freshwater ecosystems—rivers and wetlands, including floodplains, peatlands, and lakes.
- Intervention (I): The review focussed on large-scale restoration interventions, avoiding where possible small, isolated projects, to capture comprehensive ecological and societal outcomes.
- Comparator (C): The review focussed on studies that incorporate degraded or unrestored ecosystem conditions as baselines, to support a comparative analysis of restoration impacts.
- Outcome (O): The review identified improvements in ecosystem services and resulting societal benefits, explicitly recognising trade-offs or unintended consequences.

Secondary questions considered by the review identified context-specific effectiveness of measures and potential trade-offs.

2.3   Search methodology

The search methodology combined systematic database searches with targeted searches of organisational reports and grey literature. The Web of Science was the primary source for identifying peer-reviewed literature. Professional networks were also approached to identify grey literature.

Search strings leveraged specific keywords reflecting the PICO framework. Boolean operators were used to ensure targeted and efficient searches. The full details of the review methodology are set out in Appendix A.

The literature search initially identified 331 relevant journal articles and 22 reports from the grey literature. These were reviewed by the abstract for relevance. This resulted in 129 articles/reports being retained for detailed review. Additional studies were identified over the course of the review through 'snowballing' and targeted searches based on case studies already known to the authors, or to fill any identified gaps (e.g. absence of studies related to a particular region, approach, or outcome). The review also drew on similar literature reviews where appropriate (e.g. Basak et al., 2021; Kaiser et al., 2020; Schuster et al., 2024).

Notably, the initial set of articles identified by the Web of Science search was of limited value in addressing the research question as it related to many of the ecosystem services. In addition, the articles identified through the search did not cover several key case studies and examples that were known to the authors, or which became apparent through other readings. As a result, many of the articles relied upon for the review were identified through targeted searches, such as via Google Scholar, rather than via the search protocols developed as part of the QSR methodology.

Each study identified was reviewed and summarised, including by mapping the study against a framework that included:

- Geographic location
- Ecosystem type
- Scale of restoration
- Restoration type/action
- Ecological outcomes
- Societal benefits documented, including approach to quantifying the benefits
- Trade-offs / negative Impacts
- Significance to relevant global targets (UNFCCC, CBD, SDGs, etc).

Seven freshwater ecosystem services were identified as relevant, and the studies were mapped against each benefit. This allowed for collation of the evidence of the benefits of freshwater ecosystem restoration for each of the ecosystem services, as well as evidence of trade-offs.

As a final step, the confirmed benefits of freshwater restoration were mapped against key international environmental agreements based on their potential to contribute towards goals/targets under those agreements.

3 The societal benefits of restoring freshwater ecosystems

3.1 Overview

Natural ecosystems provide untold benefits for humans. These are often described as 'ecosystem services' (Millennium Ecosystem Assessment, 2005). More recently, ecosystems have been considered in terms of 'nature's contribution to people', which includes regulating, material, and non-material contributions (Multidisciplinary Expert Panel, 2023).

For the purposes of this report, we have identified seven categories of societal benefits provided by freshwater systems (Table 5). This categorisation is based on Aylward et al. (2005), with additional categories included (carbon sequestration and supporting biodiversity) based on the findings from the literature review to ensure the report captures the key benefits linked to restoration.

Table 5. Key benefits provided by freshwater systems. Source: after Aylward et al. (2005)

Benefit	Description	Example
1. Water supply	Provision of clean water for domestic, agricultural, and industrial use	Drinking water, irrigation
2. Pollution reduction	Regulation and maintenance of water purity	Filtration of pollutants, sediment control
3. Flood risk reduction	Mitigation of flood impacts through natural absorption and storage of water	Reduction in flood damage
4. Carbon sequestration and GHG fluxes	Sequestering carbon	Storage of carbon in sediments
5. Cultural and recreational values	Enhancement of cultural, social, spiritual and recreational values	Boating, fishing, tourism
6. Food security	Provision of food sources for commercial and subsistence purposes	Fish, crustaceans, molluscs, birds and eggs, turtles, edible plants
7. Supporting biodiversity	Provision of food, water and habitat for wildlife and plants	Habitat for fish and bird breeding; water for terrestrial animals.

This section considers the evidence identified though the literature review (Section 2) of the benefits to society from the restoration of freshwater ecosystems. For each of the seven categories of benefit we set out:

- The role of freshwater ecosystems in providing the benefit and why it matters.
- The evidence of a quantified increase in societal benefits due to restoration of freshwater ecosystems. The evidence is presented as a series of key findings (F1, F2, etc). Appendices B-H set out a series of tables listing relevant sources for the findings from the literature review together with a snapshot of the source/study.
- One or more case study examples of restoration projects and their benefits.

It is important to note that the benefits provided by a restoration project will be driven by the local context. While a certain approach may result in improved water supply or reduced flood risk in some circumstances, that will not always be the case.

3.2   Water supply

Freshwater restoration can increase water yields and thus water supplies, improve river flows during dry periods, and enhance the recharge of groundwater aquifers. Catchment restoration, reconnecting rivers to their floodplains or re-meandering streams, results in flows being slowed. This can result in more water infiltrating into soils and aquifers, enhancing soil moisture levels and increasing baseflows. This in turn can provide more water for people and the environment at critical times.

- In South Africa, removing invasive riparian vegetation increased annual water yield by 34.4 million m³, about 42% of the output of a new dam and for less that 20% of the cost per m³
- In Nepal, catchment restoration (reforestation, recharge ponds) improved average yield of surface and groundwater sources by 75%
- In the Upper Midwest, USA, restoration of grassland and wetlands increased baseflow by 40%
- In Ethiopia, catchment restoration increased water tables by 10-15 meters.

3.2.1   What is the role of freshwater ecosystems in water supply?

- Freshwater ecosystems are the primary sources of water for drinking, hygiene, agriculture, and industry worldwide (Millennium Ecosystem Assessment, 2005).
- Healthy freshwater ecosystems contribute to water supply by improving the availability, storage, and timing of water resources (Aylward et al., 2005). Wetlands and floodplains function as natural reservoirs, soaking up excess water in wet periods and gradually releasing it to sustain stream flows in dry seasons and to recharge aquifers (Postel, 2005).
- Freshwater ecosystems are particularly important for **baseflows,** which is flow component that comes from groundwater discharge into a watercourse. Baseflows sustain flows between precipitation events, providing a source of water for people and the environment during periods of drought.
- Water scarcity is a major challenge, and in many places, there is fierce competition for available resources. Between two and three billion people experience water shortages for at least one month per year (United Nations, 2023) and global water shortages are threatening agricultural productivity (especially irrigation-dependent production) and, as a result, global food security (IPCC, 2022).

3.2.2   What is the evidence of benefits from freshwater restoration?

F1. **Increased water yield and more reliable baseflows**: Ecosystem restoration can measurably augment water yields for human use in certain places and where the right environmental conditions recover. In South Africa's Western Cape, clearing invasive trees from rivers and riparian zones increased annual water yield by an estimated 34.4 million m³, about 42% of the output of a major new dam at a cost far lower than built infrastructure (Marais & Wannenburgh, 2008). Catchment restoration, reconnecting rivers to their floodplains or re-meandering streams results in flows being slowed. This can result in more water infiltrating into soils and aquifers, enhancing soil moisture levels and improving baseflows. Upstream land restoration in Kenya's Tana River basin is projected to raise water yields by ~4%, with dry season flows up to 15%

higher (TNC, 2015). In the Upper Midwest (USA), restoration of grassland and wetlands led to a 40% increase in baseflow and a lengthening of flow duration (Cowdery et al., 2019). Similarly, nature-based solutions like beaver dam construction can raise local groundwater levels and prolong streamflow during dry periods, increasing water storage in the landscape (Westbrook et al., 2006). However, studies of have also shown that certain interventions, such as forest restoration, regeneration, and afforestation, can result in a decrease in water yields (Filoso, 2017).

F2. **Enhanced groundwater recharge**: By increasing soil infiltration, freshwater ecosystem restoration boosts aquifer recharge. A global review of 61 projects using nature-based recharge found 50 reported significant increases in groundwater levels (Kebede et al., 2024). In Ethiopia, catchment restoration using terraces, reforestation, and soil bunds dramatically improved infiltration, with water tables in treated catchments rising by 10-15 meters. These measures reduced runoff, resulting in greater groundwater reserves and improved dry-season spring flows (Meaza et al., 2022). [2]

3.2.3   Case study – South Africa Working for Water program

Invasive alien species cause millions of dollars of damage to South Africa's economy every year and are the single biggest threat to the country's biological diversity. Furthermore, invasive plants are a major threat to water security. Invasive plants such as wattles, pines, and eucalyptus are estimated to use substantially more water per year than native vegetation, dramatically reducing baseflows and groundwater recharge. National assessments indicate that invasives could reduce South Africa's mean annual runoff by 16 % in the long term (Le Maitre et al., 2016)

In response to these challenges, the Working for Water (WfW) program was established in 1995, with the aim of clearing terrestrial alien invasive plants while also supporting rural employment and providing social services. This government run program has invested around R1 billion (USD 5.7 million) per year to remove invasives and restore catchments, involving hundreds of projects across thousands of sites covering ≈27 million hectares. The program involves a combination of mechanical and chemical methods, as well as biological control (DFFE, n.d.).

In removing invasive plants, the program has resulted in substantial improvements in water yield. A study in 2008 estimated that around 7% of riparian invasives had been cleared, resulting in an increased yield of 34.4 million m^3/year. This volume is about 42% of the yield of the new Berg River Scheme in the Western Cape. As well providing substantial additional water resources, the WfW program did so at a cost-effective rate. Total investment at that time in the WfW program was R116 million meaning that the water generated by the program cost approximately R3.4/m^3 compared with nearly R20/m^3 for water from the Berg River scheme (total cost ≈R1.6 billion). That is, catchment restoration delivered additional water at around 17% of the per unit cost of a new dam (Marais &Wannenburgh, 2008).

---

[2] As with all of the findings presented in this report, the benefits from freshwater restoration will be dependent on the context. Restoration measures will not always increase water supply. Indeed, restoration in some situations may in fact reduce the water available for human purposes (Filoso, 2017).

3.3   Pollution reduction

Healthy freshwater ecosystems maintain water quality through natural processes of filtration, sediment trapping, nutrient cycling, and contaminant breakdown. Freshwater restoration can improve water quality, resulting in significant reductions in water treatment costs and improved public health outcomes.

- Conservation and restoration of rivers and their catchments allowed the New York city to avoid construction of an $8-10 billion filtration plant as well as avoiding annual treatment costs of $365 million/year (achieved through measuring costing ~$100 million/year)
- Fencing streams to exclude cattle and revegetating riparian corridors can reduce microbial contamination from *Cryptosporidium* by 93%
- Restoration measures in the Great Barrier Reef catchments, including improved farming practices, have stopped 140,000 tonnes of fine sediment and 550 tonnes of dissolved inorganic nitrogen from entering the Reef lagoon.

3.3.1   What is the role of freshwater ecosystems in maintaining water quality?

- Freshwater ecosystems play a critical role in maintaining water quality through natural processes of filtration, sediment trapping, nutrient cycling, and contaminant breakdown. Wetlands and riparian zones can trap sediments, heavy metals, and organic pollutants, preventing them from reaching downstream water bodies and thus protecting human health and aquatic biodiversity (Millennium Ecosystem Assessment, 2005).
- Wetlands can remove up to 90% of nitrates from agricultural runoff, significantly reducing eutrophication risks that degrade water quality and harm aquatic life (Mitsch and Gosselink, 2015).
- Floodplain wetlands intercept high-flow pulses, slowing water, depositing sediments, and retaining particulate-bound nitrogen and phosphorus before they reach downstream waters. Studies of the U.S. Coastal Plain rivers shows floodplains are major regulators of sediment and nutrient transport, with substantial interception of materials otherwise exported downstream (Noe & Hupp, 2009).
- Floodplains and vegetated buffer strips reduce nutrient loading by facilitating denitrification (Hoffmann et al., 2020).
- There are major implications for societies when freshwater ecosystems become polluted or degraded. Contaminated water can transmit cholera, dysentery, and other waterborne diseases, contributing to roughly one million preventable deaths each year (WHO, 2023). Water pollution severely threatens biodiversity in freshwater ecosystems, reducing species abundance, altering community structures, and leading to widespread species declines. (Dudgeon et al., 2006).
- Pollution imposes heavy financial burdens. In Shanghai, water purification costs doubled over a decade due to increased contamination from organic pollutants and heavy metals in the Yangtze River Basin (World Bank, 2019b). Rising nitrate levels in the Thames River

resulted in Thames Water investing approximately £250 million to upgrade facilities specifically designed to remove nitrates and pesticides (DEFRA, 2021).

3.3.2 What is the evidence of pollution reduction from freshwater restoration?

F3. **Improved water quality**: Wetlands and riparian buffers can trap sediments, take up excess nutrients, and break down contaminants before water reaches rivers or aquifers. Restoration of degraded streams and wetlands can result in improvements in key water quality parameters. Common findings include reductions in nutrient concentrations, increased dissolved oxygen, lower turbidity, and reduced algal blooms or eutrophication in downstream waters. (Kaiser et al., 2020; Russi et al., 2013). Restored floodplains can capture agricultural runoff, allowing suspended sediments and fertilizers to settle out from floodwaters and be taken up by floodplain vegetation (Paul et al., 2018; Waltham et al., 2019). Re-meandering a stream increases contact time between water and the streambed and its biota, enhancing denitrification and other purification processes. This enhances overall ecosystem health and the reliability of water sources for agriculture and fisheries. Restoration measures have stopped 140,000 tonnes of fine sediment and 550 tonnes of dissolved inorganic nitrogen from entering the Great Barrier Reef lagoon (DCCEEW, 2023).

F4. **Reduced water treatment costs**: Where catchment degradation has resulted in pollution of water sources, restoration can significantly reduce the need for expensive water treatment infrastructure and ongoing water treatment costs (Emerton et al., 1999; TNC, 2015). Protection and restoration measures in the catchments that provide the bulk of the drinking water supply for New York City avoided the need for $8-10 billion filtration plant and $365 million/year treatment costs (National Academies of Sciences, Engineering, and Medicine, 2020).

F5. **Improved drinking water and public health outcomes**: Restoration interventions have led directly to cleaner drinking water sources by reducing turbidity, pathogens, and nutrient runoff (Bryan et al., 2009; National Academies of Sciences, Engineering, and Medicine, 2020). This directly benefits public health by lowering the risks associated with contaminated drinking water. Fencing streams to exclude cattle and revegetating riparian corridors can reduce microbial contamination, including a 93% reduction of *Cryptosporidium* (South Australia EPA, 2008).

3.3.3 Case study – New York watershed conservation and restoration

The Catskill/Delaware catchment provides roughly 90% of the water supply to New York City. The catchment watershed historically provided pristine, unfiltered drinking water, but during the 1990s development, agricultural runoff, and aging infrastructure were threatening water quality.

Facing stringent federal drinking water regulations and the need to potentially build a filtration plant, the city chose to implement an extensive catchment restoration program. Around USD$2.5 billion has been invested in the program between 1997 and 2020, with key measures including:

- Land Acquisition & Protection: New York City invested in an extensive land acquisition program, acquiring over 50,000 hectares of critical catchment land to prevent development.
- Stream Management: The city and its partners undertook stream restoration to stabilize eroding banks and revive riparian buffers, with the goal of reducing turbidity in waterways.

- Agricultural Best Practices: Nearly all farms in the watershed joined voluntary programs to adopt best management practices (BMPs), such as nutrient management and stream fencing, to curb runoff of nutrients, pathogens, and sediment

The restoration program has maintained water quality while also delivering wide societal benefits. A comprehensive review of the program by the National Academies of Sciences, Engineering and Medicine concluded that the program has "admirably supported watershed water quality sufficient for compliance with [US Environment Protection Agency requirements to maintain an exemption from filtration requirements], with strong indications that it will remain effective into the future".

Restoration has proven substantially more cost-effective as a means for providing drinking quality water compared to other treatment options. The capital cost for filtering the system is estimated between USD $8 billion to $10 billion plus annual operation and maintenance costs of about $365 million. This compares to a cost of roughly USD $100 million/year for the restoration program.

Beyond water supply, the restoration program has yielded co-benefits for communities and the environment. Upstate rural areas gained upgraded utilities (wastewater systems, septic replacements) and economic support through farm programs and land compensation. The program also conserved open space and biodiversity: large swaths of forest and wetland habitat remain intact, supporting recreation and wildlife as well as flood mitigation.

Source: National Academies of Sciences, Engineering, and Medicine. 2020

3.3.1 Case study – Riparian Restoration to Protect Drinking Water in South Australia

The Myponga Reservoir catchment supplies drinking water to the city of Adelaide, but intensive agriculture and livestock grazing have long contributed to degraded riparian zones and elevated risks of *Cryptosporidium* contamination. Recognising the link between catchment condition and public health, South Australian authorities implemented a Myponga Watercourse Restoration Project (2000–2007), later continued under the Adelaide and Mount Lofty Ranges NRM Board.

The restoration program delivered substantial on-ground works: fencing stock out of streams, revegetating riparian corridors, installing off-stream watering points, and controlling weeds and erosion. By 2007, approximately 23 km of waterways (8–10% of the network) had been treated. Modelling suggested these interventions reduced total suspended sediment inputs to the reservoir by around 12%, with reductions of up to 16% in intensively treated sub-catchments. These outcomes highlight measurable improvements in source water quality attributable to ecological restoration.

Building on this, Bryan et al. (2009) undertook an adaptive management study that modelled both the existing restoration works and additional interventions such as expanded riparian revegetation and improved grazing management. The modelling demonstrated that such measures could significantly lower pathogen (*Cryptosporidium*) loads reaching the reservoir. By reducing faecal inputs and sediment-associated transport of oocysts, catchment restoration was shown to be a cost-effective complement to engineered water treatment, directly safeguarding public health.

Source: South Australian Environment Protection Authority (2008); Bryan et al., (2009).

3.4   Flood risk reduction

Freshwater ecosystems, including rivers, floodplain wetlands and upstream forests, play a crucial role in buffering communities from floods by storing water and slowing water flow. Freshwater restoration can slow catchment run-off by providing more space for floodwaters. This slows the movement of flood flows, reducing flood peaks and the damage caused by flooding. Restoration can provide a cost-effective means for reducing flood risk and improving climate resilience.

- Work in the Yangtze basin has resulted in an additional 2,9700 km2 of restored floodplains with a floodwater retention capacity of 8 billion m3
- Restoring lost floodplains in the Upper Mississippi Basin could store ~48 billion m3 of floodwater and avoid an estimated $16 billion in flood damages.
- $1 invested in floodplain restoration today can avoid about $5 in future flood losses.

3.4.1   The role of freshwater ecosystems in reducing flood risk

- Freshwater ecosystems play a crucial role in buffering communities from floods. Natural river systems, floodplain wetlands and upstream forest ecosystems can reduce flood risk by storing water and slowing water flow (IPCC, 2022). For example, in Vermont (USA), the Otter Creek wetlands saved one town up to 78% of potential flood damages, avoiding an estimated $1.8 million in losses during a single extreme storm. Across multiple events, the town saw over 50% reduction in flood-related property damage due to its intact floodplain. These avoided losses translate into substantial economic benefits and lower disaster relief costs for society (Watson et al., 2016).

- When rivers are connected to their floodplains, downstream flood peaks are lower and arrive later, which diminishes flood risk. Restoration measures such as re-meandering channels, establishing (or re-establishing) floodplain wetlands, and removing or setting back levees increase water retention in the landscape. In contrast, rivers constrained by dikes and drained wetlands can exacerbate flood risk by increasing the speed of water flows and the size of flood peaks (Acreman & Holden, 2013).

- Floods affect more people than any other natural hazard, with increasing frequency and severity due to climate change, urbanization, and habitat degradation (IPCC, 2022). Floods cause tens of billions of dollars in economic losses annually (Our World in Data, 2024) and result in significant loss of life (UNDRR, 2015; 2022).

3.4.2   What is the evidence of flood risk reduction from freshwater restoration?

F6. **Attenuation of flood peaks and cost-effective flood management**: Reconnecting rivers to floodplains and restoring wetlands markedly reduces flood surges (Serra-Llobet et al., 2022). Even small wetlands can reduce surface runoff by 30-50% and thereby lower local flood crest levels by 10–25% compared to non-wetland areas (Yang et al., 2024). Large-scale levee setbacks similarly give floodwaters somewhere to go, reducing downstream peak flows and water levels. Reducing flood risks via nature-based solutions is often more cost-efficient than hard infrastructure. Restoring floodplains can eliminate the need for ever-higher levees or complement engineered defences at a fraction of the cost (Dottori et al., 2023; Vicarelli et al.,

2024). In the Yangtze basin, the removal of levees, the restoration of wetlands, and upstream reforestation has resulted in an additional 2,9700 km^2 floodplain restored with a floodwater retention capacity of 8 billion m^3 (Pittock & Xu, 2011).

F7. **Reduced flood damages**: By absorbing excess water and reducing flood peaks, restored floodplains and wetlands significantly reduce the damage caused by floods. Restoration can reduce the number of people and extent of infrastructure that is exposed to flood risk, reducing the costs incurred by individuals and governments as a result of flooding (World Bank, 2019a; Dottori et al., 2023). Reduced flood risk can also translate into reduced insurance costs. Modelling of the benefits of restoring lost floodplains in the Upper Mississippi Basin suggested the potential for floodplains to store ~48 billion m3 of floodwater and avoid an estimated $16 billion in flood damages (Hey et al., 2004).

3.4.3   Case study – Room for the River, Netherlands

With twenty-five percent of the country lying below sea level and approximately two-thirds of the country at risk of flooding, the Netherlands has a long history of flooding and flood management. Undertaken from 2006 to 2015, the Room for the River program was implemented by the Duch government in response to major floods in 1993 and 1995 as a nationwide initiative to reduce flood risk by restoring river–floodplain connectivity. The primary objectives of the program were to reduce the consequences of flooding, as well as the probability of failure of existing embankments. Secondary objectives related to delivering ecological and social benefits.

This new approach to flood management involved more than 30 projects along the Rhine, Meuse, Waal, and IJssel rivers, including levee setbacks, floodplain lowering, creation of side channels, removal of obstacles (including agricultural embankments, old groynes, and elevated tracks), and relocation of infrastructure. Modelling and monitoring demonstrated that these measures expanded the rivers' capacity from 15,000 m³/s to 16,000 m³/s, which has also resulted in the lowering of the 1:1250 per year flood levels by 0.3 m on average on the Rhine. This has primarily been achieved by adding 4,400 ha of extra floodplain area to the existing 28,800 ha along the Netherlands' Rhine branches.

In addition to flood risk reduction, the projects have revitalised degraded floodplains, created new nature reserves and provided recreational opportunities.

Source: Klijn et al. (2018); Klijin et al., (2013); Van Alphen (2019)

3.4.1   Case study – Restoring Floodplains for Flood Risk Reduction in the Yangtze Basin, China

The Yangtze River basin is home to over 400 million people and has long been exposed to catastrophic flooding. The 1998 flood, which killed more than 4,000 people and displaced 14 million, marked a turning point in China's flood management policy. Until then, management had relied heavily on hard infrastructure such as levees and polders. Following the disaster, the government adopted a new approach, involving a shift towards an integrated strategy of floodplain restoration, wetland reconnection, and reforestation.

Between 1998 and the mid-2000s, thousands of kilometres of embankments were removed or set back, and farmland within polders was returned to floodplain wetlands, particularly around Dongting and Poyang Lakes. In total, more than 2,900 km² of floodplain was reconnected to the Yangtze

system. Parallel efforts in the upstream catchments involved large-scale reforestation to reduce runoff and soil erosion.

These measures have substantially increased floodwater retention capacity and reduced downstream flood peaks. At Dongting Lake, an area of 1,700 km^2 with a floodwater retention capacity of 3.5 billion m^3 was restored while at Poyang Lake, an area of 1,200 km^2 with 4.5 billion m^3 of floodwater retention capacity was restored. These changes have reduced the probability of levee overtopping in densely populated downstream regions. In addition to lowering flood risk for tens of millions of residents, the changes have revived wetland biodiversity and are supporting rural livelihoods through fishing, grazing, and ecotourism.

Source: Pittock & Xu (2011)

3.5   Carbon storage and greenhouse gas (GHG) fluxes

Restoration turns degraded wetlands from major carbon sources into durable carbon sinks, preventing vast CO_2 losses and locking carbon in soils for the long term. While restoration can initially result in increases in methane, these are temporary and outweighed by avoided CO_2 and N_2O emissions, delivering strong net climate benefits after only a few years. Soil carbon storage rises substantially with restoration, especially in rewetted peatlands and floodplains, though natural levels are rarely matched.

Global mitigation potential is large: restoring priority wetland and river systems could offset a meaningful share of annual global emissions at relatively low cost. Protecting and restoring wetlands is among the most effective natural climate solutions, combining long-term carbon storage with additional ecological and societal benefits.

- Global-scale reviews and modelling show that wetland and peatland restoration can prevent up to hundreds of petagrams of CO_2 emissions by 2100, sequester over 1 Pg CO_2 annually, and cut net warming potential of wetlands by more than 60%.
- In Israel and China, rewetting of drained wetlands reduced CO_2 losses and increased soil organic matter (SOM).
- Numerous rewetting projects in Europe show consistent reductions in CO_2 emissions and avoided losses, though methane often rises. Benefits grow over decades, with rewetted peatlands shifting towards carbon sinks; prioritising highly degraded sites maximises mitigation potential.
- Field studies in the United States and Canada demonstrate that raising water tables in peatlands and floodplains cuts CO_2 losses by up to 90%, with restored sites showing markedly lower net GHG fluxes.

3.5.1   The role of freshwater ecosystems in carbon sequestration

- Freshwater ecosystems are critical in the global carbon cycle. These systems are often referred to as teal carbon ecosystems because of their distinct role compared with "blue carbon" (coastal) or "green carbon" (terrestrial forests).
- Wetlands (including both freshwater and coastal systems) store around one-third or more of global soil organic carbon (Gorham, 1991; Zou et al., 2022). Soil organic carbon (SOC) storage depends on hydrology, vegetation, and sediment supply. For example, permanently saturated peat soils accumulate much larger carbon stores than seasonally wet systems (Pendea et al., 2023).
- Teal carbon ecosystems hold extensive carbon stocks, mainly in peat soils. Peatlands cover around 3% of the earth's land surface, but store around 20% of the total global soil organic carbon. Globally, peatland drainage is responsible for over 3.5% of anthropogenic GHG emissions (Sapir et al., 2025).
- Studies suggest significant global carbon sequestration by wetlands, influenced by hydrology, temperature, nutrient status, and vegetation (Mitsch et al., 2013; Carnell et al., 2018; Zhang et al., 2025). Regionally, sequestration rates vary widely, with depressional wetlands, riverine systems, and forested wetlands all showing distinct carbon accumulation potentials (Bernal & Mitsch, 2011; Carnell et al., 2016).

- The conditions that favour carbon storage in wetlands also stimulate methane production (Chen et al., 2024; He et al., 2025). As such, while teal carbon systems are long-term carbon sinks, there are short-term trade-offs: CH_4 often increases after rewetting, and there are still major knowledge gaps for CH_4 and N_2O fluxes in freshwater wetlands (Zhang et al., 2025; Kumar et al., 2025).

- The most effective management strategy for improving carbon storage and sequestration is to restore or maintain hydrological conditions that preserve long-term saturation. Interventions such as drain blocking, raising water tables, and floodplain reconnection reduce aerobic decomposition, restore sedimentation, and rebuild soil carbon stores (Joosten et al., 2012; Schwerk et al., 2025).

- Land-use change from agriculture back to wetlands can reduce net emissions and rebuild carbon stocks, but requires careful planning of water levels, vegetation, and socio-economic transitions (Schwerk et al., 2025; Hashemi et al., 2025). Protecting intact peatlands and wetlands remains the most efficient way to maintain carbon storage and minimise new emissions (Taillardat et al., 2020; Schuster et al., 2024).

3.5.2 What is the evidence of carbon storage and GHG flux benefits from freshwater restoration?

F8. **Rewetting of peatlands is a favoured wetland restoration measure to achieve carbon storage and GHG benefits.** This is because: (i) they have a high natural carbon storage capacity, (ii) large areas of peatland have long been subjected to draining, becoming ongoing sources of carbon to the atmosphere, and (iii) rewetting to increase carbon storage capacity and prevent further carbon loss is relatively straightforward (Leifeld & Menichetti, 2018). Although efforts to preserve or rewet peatlands are intensifying, restoration has been applied to only a small fraction of drained peatlands. For example, in Europe, less than 1% of the drained peatland has been rewetted over the past decades (Heinrich Boll Stiftung, 2023). On degraded peatlands, blocking of drains could be sufficient to restore their function as carbon stores. For these reasons, peatlands have been prioritized globally for wetland restoration. Cases of peatland restoration accompanied by carbon and GHG monitoring have been reported across Asia, Europe, Canada and USA (Armstrong et al., 2022; Schwerk et al., 2025; Sapir et al., 2025), with field studies in the United States and Canada demonstrating that raising water tables in peatlands and floodplains cuts CO_2 losses by up to 90% (Richardson et al., 2023).

F9. **Emissions from degraded wetlands could be substantially reduced through restoration.** The potential of global-scale wetland restoration is significant. For example, one study found that restoration across 355–484 million hectares of wetlands could sequester 3—9% of current global carbon emissions (Hashemi et al., 2025). Global modelling of wetland carbon storage and GHG fluxes has revealed that even if degradation ceased today, existing degraded wetlands would continue to emit CO_2 to the atmosphere (up to around 400 Pg by 2100); much or all of this could be avoided by restoration (Zou et al., 2022). Studies have also suggested that large wetland areas (>100 ha) and wetlands restored in warm (temperate and tropical) climates recovered biogeochemical functioning more rapidly than smaller wetlands and wetlands restored in cold climates (Moreno-Mateos et al., 2012).

3.5.3 Long-term Effects of Drainage and Rewetting on Peatlands in the Hula Valley, Israel

The Hula Valley peatland in Israel illustrates the long-term effects of drainage and rewetting in a warm climate. The marsh was drained in 1957 for agriculture, leading to rapid peat oxidation and carbon loss. A hydrological restoration project in 1994 partially rewetted the site, achieved by raising and stabilizing the groundwater table about 1 m below the surface. This partial restoration was designed to reduce soil oxidation, halt fires, and preserve organic matter. This created three peat horizons: a long-drained upper layer, a mid-section rewetted for ~30 years, and a deeper pristine section never exposed to drainage.

Drainage reduced the percentage (by weight) of SOM in the top meter of the soil from ~68% to 21% over 66 years. By contrast, the rewetted zone preserved 33% of SOM (again, by weight) and the pristine layer retained 64%. Experiments showed that rewetted peat had higher short-term CO_2 fluxes per unit carbon than either drained or pristine peat. However, long-term modelling indicated that rewetting slowed degradation and stabilized carbon. Estimated CO_2 emissions declined from ~94 t C ha^{-1} yr^{-1} in the early decades after drainage to ~28 t C ha^{-1} yr^{-1} today.

This case demonstrated that rewetting even after prolonged degradation can significantly reduce further GHG losses, preserve organic matter, and stabilize carbon stocks, although short-term flux responses may vary. The study highlights that warm-climate peatlands behave differently from boreal systems, but the principle that restoring high water tables reduces long-term carbon loss is broadly applicable to peatland management elsewhere.

Source: Sapir et al, 2025

3.5.4 Case Study: GHG Dynamics in Mayberry wetland, Sacramento–San Joaquin Delta, California

The Mayberry wetland in California's Sacramento–San Joaquin Delta was restored in 2010 on formerly drained grassland pasture. The project aimed to reduce subsidence, enhance habitat, and promote long-term carbon sequestration. Restoration involved re-flooding with a carefully engineered bathymetry of channels, ponds, and shallow zones to support diverse aquatic vegetation.

Over a decade of continuous measurements of CO_2 and CH_4 showed an initial spike in methane emissions, with exceptionally high fluxes initially, followed by a steady decline. This decline coincided with vegetation infilling, which likely enhanced root oxygenation and methane oxidation. Analysis of the early years of high methane emissions alone suggested a delay of nearly 200 years before the site would reach net climate benefit. However, with the longer dataset captured over the 10-year period, this estimate dropped to ~50 years, underscoring the importance of long-term monitoring in assessing climate outcomes of restoration.

This case demonstrated that restored wetlands may emit large amounts of methane immediately after flooding, but emissions can decline markedly over time as vegetation and biogeochemical processes stabilize. Long-term datasets are essential to capture these trends, refine carbon accounting, and demonstrate the net climate mitigation value of re-flooded peatlands.

Source: Delwiche et al, 2025

3.6   Food security

Freshwater restoration supports food security through increased food production and income generation. Community co-management and protected breeding areas have been shown to increase fish abundance and enable predictable harvests. Removing barriers and re-establishing seasonal flood regimes can restore habitats that underpin fish recruitment and support flood-compatible agriculture.

Programs report substantial increases in catch, catch per unit effort and fisher revenues; documented recoveries of migratory runs with clear fishery implications; and the resumption of reed and related wetland harvests with positive local economic returns.

- In Malawi, community-managed fish refuges increased fish species richness by approximately 24%.
- In Bangladesh's Hail Haor wildlife sanctuary, co-managed fish refuges in the wetlands and seasonal closures increased fish catch by about 88% and raised fish consumption among poorer households.
- In Nepal's Lake Rupa, cooperative action increased annual fish production from 18.5 tonnes to around 70 tonnes.
- On Maine's Penobscot River in the United States, dam removals and fish-passage upgrades have enabled annual returns of more than five million river herring, revitalising river-dependent fisheries.

3.6.1   The role of freshwater ecosystems in food security

- Aquatic foods are central to local diets and nutrition. Inland and small-scale fisheries provide highly bioavailable protein and essential micronutrients to hundreds of millions of rural and peri-urban consumers, yet their contributions are often overlooked in food-security policy debates (Lynch et al., 2016; McIntyre et al., 2016; Arthur et al., 2023). In northern Australia, magpie goose, which relies on healthy sedgeland wetlands, is traditionally an important food source for Aboriginal peoples (Delaney et al, 2009). Juvenile forms of several freshwater fish species ("whitebait") are an important traditional food on the Waikato River, New Zealand especially for Māori, and now command high prices as a luxury food (Abell et al., 2022; Pingram et al., 2021).
- Rivers underpin large-scale food provisioning: At least 12 million tonnes of freshwater fisheries harvest per year comes from rivers (Basak et al., 2021, UN-Water, 2018). Dependence on inland fisheries is greatest in poorer and undernourished populations where alternatives are scarce. Safeguarding rivers and lakes is therefore directly linked to local food security and livelihoods for poverty reduction (McIntyre et al., 2016). Small-scale fisheries and wetland products support incomes and resilience. Direct sales of fish, coupled with processing and petty trade (often by women), provide cash income and buffers against shocks—especially where co-management improves access and predictability (Coates et al. 2013; HLPE, 2014; Funge-Smith & Bennett, 2019; Coates, 2023; Arthur et al., 2023).
- Most inland fish are consumed locally, linking harvests directly to household food security especially in South America, Asia and Africa. Small-scale fisheries largely provision nearby markets and households; improving local access, governance and value-chains therefore directly translates into better diets and stability of supply (Arthur et al., 2023).

- In South and Southeast Asia, floodplain ecosystems are tightly coupled to livelihoods. Empirical work in Bangladesh shows that multi-use wetlands (e.g., haor systems) contribute substantial food and income benefits for local communities, underscoring the centrality of floodplain ecosystem functions to household well-being (Rahman & Minkin, 2007; Thompson, 2008).
- Water is a binding constraint—and lever—for food systems. Water quantity, quality, timing and access shape every stage of food systems (production, processing, cooling, storage) and will increasingly determine outcomes under climate change; integrated action on water is therefore necessary to safeguard availability, access and stability of food (Ringler et al., 2022). For example, seasonal flow pulses and floodplain connections create spawning, nursery and feeding habitat for inland fish, supporting recruitment and year-to-year availability (Wohl et al., 2015; Vermaat et al., 2016; Coates et al., 2013).

3.6.2   What is the evidence of food security benefits from freshwater restoration?

F10.   **Restoration through community co-management and establishing fish refuges rapidly rebuilds fish stocks and increases fisher incomes.** In the western Brazilian Amazon, protected oxbow lakes averaged ~305 fish (arapaima) er lake versus ~34 in subsistence-use and ~9 in open-access lakes, despite protected lakes being smaller (Campos-Silva & Peres, 2016). Data from 30 communities showed co-management increased catch in protected lakes by 12–13% and raised fishing revenue by 63% relative to open-access (Silva et al., 2025). In Bangladesh's Hail Haor wetland, a package of refuges, seasonal closures and co-management increased fish catches by ~88%, raised fish consumption among poorer households by ~45%, and returned strong economics (benefit–cost ratio ~4.7) (Coates, 2023).

F11.   **Reconnecting rivers (dam removals and fish passage) restores migratory fish runs that underpin regional fisheries.** On Maine's Penobscot River, barrier removals and passage upgrades have enabled sustained resurgence of sea-run fish: in 2024, Milford fishway counted >5.48 million river herring—the highest recorded —supporting direct consumption and the bait fishery (Atlantic Salmon Federation, 2024). State commercial landings data corroborate a broader recovery of alewife supply across Maine (Maine Department of Marine Resources, 2025). Fish passage improvement on the Waikato River and its tributaries, New Zealand, improved fish (īnanga) migration and spawning conditions to support whitebait fishery.

F12.   **Restored freshwater wetlands and reconnected floodplains can deliver quantified food provisioning (as well as fibre and energy) that buffers household food security.** In Romania's Danube Delta, breaching dykes to reconnect ~3,600 ha at Babina and Cernovca rapidly re-established floodplain habitats, supporting spawning/nursery fish and enabling reed harvesting and grazing. (WWF, 2010; Hein et al., 2016). In the Kakadu floodplains of Northern Territory, Australia, restoration of tropical wetlands led to increased numbers of magpie goose, traditionally an important food source for Aboriginal peoples (Bayliss & Ligtermoet, 2018).

3.6.3   Case study – Juruá River of Western Brazilian Amazonia

Effectively managing protected freshwater areas can restore sustainable resource use. Along the Juruá River, a community-based management (CBM) system emerged to curb escalating commercial fishing pressure by restricting large boats from community lakes and prioritising the recovery of the emblematic arapaima, a large fish species (*Arapaima gigas*). Lakes are zoned as open-access,

subsistence-use, or protected (stock-recovery/managed harvest), creating clear rules that local communities can enforce and benefit from (Campos-Silva & Peres, 2016).

Monitoring across 83 oxbow lakes spanning ~500 km showed that management category strongly predicted outcomes: patterns of CBM explained 71.8% of the variation in arapaima population. Mean counts were 304.8 (±332.5) in protected lakes, 34.1 (±24.4) in subsistence-use lakes, and 9.2 (±9.8) in open-access lakes—despite open-access lakes typically being larger (Campos-Silva & Peres, 2016). These differences, derived from repeated annual counts, illustrate the scale of biological recovery when access is regulated and local stewardship is strong.

Fishery performance data point in the same direction. Across 1,607 fishing trips by 198 fishers in 30 communities and 74 lakes, co-management increased fish catch in protected lakes by 12–13% compared with subsistence-use or open-access lakes, and fishing revenue was 63% higher than in open-access lakes (Silva et al., 2025). Recent studies in comparable floodplain systems also link higher catch per unit effort to effective governance and protection. Together, these lines of evidence indicate that CBM can rebuild stocks and translate ecological recovery into tangible livelihood gains for fishing households.

3.6.4 Case study – Meghna Basin, Bangladesh: hilsa refuges & co-management

Bangladesh implemented an integrated restoration package for hilsa (*Tenualosa ilisha*)—a keystone food fish—including river refuges, seasonal closures, gear and buyer rules, targeted enforcement, and compensation/alternative livelihoods for affected fishers. The package was designed to protect migrating adults and juveniles, maintaining community support through co-management and social safeguards.

Impact evaluation found incomes rose by 86.19% and assets by 63.99% in intervention households. The programme's internal rate of return was ~32.8% (Mohammed et al., 2025). These results show that carefully designed refuges and closure regimes, coupled with enforcement and livelihood support, can boost fish supply and household welfare at scale.

Beyond the headline figures, the case demonstrates process lessons that matter for replication: aligning temporal closures with spawning and migration windows; using compensation to reduce short-term hardship; and embedding monitoring so that gains in catch and income can be tracked. In combination, these elements provide a model of governance-led river restoration that measurably advances both fisheries production and food-security outcomes.

3.7   Cultural and recreational values

Freshwater restoration can increase outdoor recreation and tourism, strengthen cultural and spiritual connections, and improve aesthetic qualities of freshwater systems, contributing towards community well-being.

- Restoration of an urban park in Singapore saw annual visitation to the park double from ~3 million to 6 million
- Decommissioning a dam and establishing a wetland reserve in Victoria, Australia led to double the numbers of visitors for walking, cycling birdwatching, and canoeing
- Removal of dams on the Elwha River in Washington, USA, reopened over 110 km of salmon habitat, allowing the Lower Elwha Klallam Tribe to renew salmon fishing traditions and spiritual ceremonies that had been suppressed for a century
- A USD 10 million investment in restoring Muskegon Lake, USA,0 resulted in total local economic benefits of ≈ USD 60 million through increased tourism and raised property values.

3.7.1   The role of freshwater ecosystems in supporting cultural and social values

- Freshwater ecosystems play a fundamental role in supporting diverse cultural, social, and aesthetic values that underpin human well-being. Globally, freshwater ecosystems serve as focal points for recreation, tourism, education, and community engagement. They support physical and mental health, social cohesion, and economic opportunities (MEA, 2005).
- Rivers and lakes are integral to cultural identity and heritage, supporting traditional practices, festivals, ceremonies, and livelihoods, particularly for indigenous peoples who maintain deep spiritual and cultural connections to water bodies (UNESCO, 2021; 2023; 2024).
- Aesthetic appreciation of freshwater landscapes enhances quality of life and promotes mental well-being. This is particularly important in urban areas where rivers and wetlands provide access to (often limited) natural settings (Völker & Kistemann, 2011).

3.7.2   What is the evidence of cultural and social benefits from freshwater restoration?

F13.   **Increased outdoor recreation and tourism**: Restoring rivers to a more natural state has been shown to increase recreation opportunities and usage, including more people swimming, paddling, boating, fishing, and viewing wildlife. Free-flowing, healthier rivers also attract visitors, bringing economic benefits to communities and local businesses. Restoration of Muskegon Lake in Michigan, USA resulted in total local economic benefits of ≈ USD 60 million NPV benefit, primarily from increased tourism (Isely et al., 2018). Restoration of the Isar River in Munich, Germany allowed for swimming in the river for the first time in decades (EEA, 2016).

F14.   **Strengthened cultural and spiritual connections**: Freshwater restoration can rejuvenate cultural values tied to rivers and lakes. Many indigenous and local communities have deep spiritual or historical relationships with specific waters and species. River restoration, such as improving flows or removing barriers, can restore access to culturally important species and sites. For instance, the removal of dams on the Elwha River in Washington, USA, reopened over 110 km of salmon habitat, allowing the Lower Elwha Klallam Tribe to renew salmon fishing

traditions and spiritual ceremonies that had been suppressed for a century (NOAA Fisheries, 2024).

F15.   **Improved aesthetic quality and community well-being**: Restoration typically makes freshwater environments more visually appealing and enjoyable. By reintroducing natural features (like meanders, riffles, riparian vegetation and clear water) restoration projects create greener, more scenic landscapes. Urban river restorations in particular transform waterways into attractive public spaces, enhancing recreational spaces, improving community pride, and reconnecting people with their local environment. Aesthetic enhancements contribute to public well-being, including improved mental health. Restoration of a drainage canal in Singapore resulted in a doubling of visitor numbers and strong community support for the social benefits arising (Koh et al., 2022).

3.7.3   Case study – Singapore Active, Beautiful Clean Waters Programme

Singapore's Active, Beautiful, Clean (ABC) Waters Programme, launched in 2006 by the Public Utilities Board (PUB) Singapore (PUB Singapore, 2018), sought to transform the city's utilitarian canals and drains into multifunctional rivers and lakescapes. Motivated by the dual pressures of climate change (more intense rainfall and rising flood risks) and the need for high-quality public spaces in a dense urban environment, the programme adopted water-sensitive urban design approaches that sought to deliver flood resilience, ecological health, and community benefits simultaneously.

The flagship project under the program was the Bishan-Ang Mo Kio Park, where a 2.7 km stretch of the Kallang River was converted from a concrete canal into a meandering naturalised river. The restoration process created a wide floodplain that can accommodate storm surges, increasing flood conveyance by around 40% while reducing flood risk to surrounding neighbourhoods. The rejuvenated park has become one of Singapore's most visited green spaces, attracting an estimated 6 million visitors annually, double previous visitation numbers. Economic analysis also suggests a significant increase in surrounding property values, reflecting the amenity and environmental improvements.

Source: Tan & Loke (2012), PUB (2018), Koh et al. (2022)

3.8   Biodiversity and supporting ecosystems services

Restoring rivers, lakes and wetlands delivers measurable biodiversity gains and re-establishes the ecosystem functions that sustain them. Addressing the dominant drivers of degradation—such as reconnecting rivers to floodplains, managing water regimes to mimic natural seasonality, removing barriers, re-meandering channelized reaches, and rewetting drained wetlands—consistently show recovery across multiple taxa. Hydrological reconnection and habitat restoration can rebuild bird assemblages at internationally significant sites, reopen migration corridors for native fishes, and enable the return of specialist wetland plants and dependent fauna.

- Partial reflooding of the Waza–Logone floodplain (Cameroon) produced large increases in waterbirds (species-level gains of +135% to +744%) and expanded typical annual flood extent by about 1,000–1,500 km².
- Hydrological restoration at Ichkeul National Park (Tunisia) has supported wintering populations in the order of 100,000–200,000 birds in typical years, and up to 300,000 in some years.
- At East Dongting Lake (middle Yangtze River, China), floodplain restoration through changes to dykes yielded higher wintering waterbird richness, density and diversity.
- In the United States, basin-scale barrier removal on the Elwha River reopened historical habitats, with eight of nine migratory salmonid species upstream of former dams within five years; on the Kissimmee River, floodplain wetland area more than doubled within two years of initial re-meandering works.

3.8.1   The role of freshwater ecosystems in biodiversity and supporting ecosystem services

- Freshwater biodiversity is concentrated yet declining rapidly. Rivers, lakes, wetlands and floodplains concentrate global biodiversity and support specialist, migratory and threatened taxa, including approximately 30% of all vertebrate species and more half of the world's fishes. Yet many groups show persistent declines driven by habitat loss, altered flows, pollution, invasive species, overexploitation and climate change (IPBES, 2019; Reid et al., 2019; Tickner et al., 2020).
- Connectivity and natural flow variation underpin biodiversity. Only about 37% of rivers longer than 1,000 km remain free-flowing along their full length (~23% reach the ocean unimpeded), illustrating the extent of fragmentation. The natural flow regime structures habitat heterogeneity and enables life-cycle completion; maintaining longitudinal and lateral connectivity is therefore essential for conserving diversity (Grill et al., 2019; Poff et al., 1997).
- Wetlands are pivotal for species and processes but continue to shrink. Around 21% of global wetland area has been lost since 1700, with direct consequences for wetland-dependent biota and the ecological processes that sustain them (Fluet-Chouinard et al., 2023, Convention on Wetlands, 2021).
- Biodiversity and ecosystem services are co-produced by the same processes (Rey Benayas et al., 2009). The ecological dynamics that support species—flow and sediment regimes, connectivity and wetland hydrology—also underpin supporting and regulating services such as flood attenuation, baseflow support, water purification and climate regulation, alongside provisioning

services such as inland fisheries and wetland materials (Opperman et al., 2010; IPBES, 2019). As the same processes that sustain biodiversity also generate services such as inland fisheries and the harvest of wetland materials, biodiversity recovery often coincides with improved provisioning outcomes.

3.8.2   What is the evidence of benefits from freshwater restoration for biodiversity and supporting ecosystem services?

F16.   **Hydrological reconnection and managed water regimes drive multi-taxon recovery.** Where floodplains are reconnected and water levels managed to mimic seasonal variation, biodiversity responses are strong and consistent: on Cameroon's Waza–Logone floodplain, partial reflooding via reopened distributaries expanded typical annual flood extent by ~1,000–1,500 km² and increased waterbirds markedly, with species-level gains of ~+135% to +744% (Loth, 2004; Scholte et al., 2006). At East Dongting Lake (China), dyke works and water-level management produced higher wintering waterbird richness, density and diversity in restored units relative to controls over 2012/13–2019/20 (He et al., 2021; Zhang et al., 2021). Tunisia's Ichkeul National Park shows recovery of flood-pulse function and large wintering waterbird assemblages under hydrological management (IUCN, 2020; UNESCO World Heritage Centre, 2010; Hamdi et al., 2012). In Australia, managed environmental flows sustained very large colonial nesting events in the Macquarie Marshes and Gwydir Wetlands (Brandis et al., 2023; Spencer et al., 2023), and improved multi-taxon outcomes (Watts et al., 2022).

F17.   **Removing barriers restores native fish assemblages and aquatic communities.** Connectivity restoration has yielded rapid fish responses in a range of different settings: removal of two large mainstem dams on the Elwha River reopened >100 km of habitat, with eight of nine migratory salmonid species documented upstream within five years (Brenkman et al., 2019; Duda et al., 2021). A multi-site assessment of small dam removals in Massachusetts found improvements in water quality and biota within ~1–5 years (Abbott, 2023). In Asia, low-head dam removal on the Jidu River increased upstream fish richness and abundance and let to fish communities more similar to free-flowing controls (Ding et al., 2019).

F18.   **Large-scale river and floodplain reconnection delivers ecosystem-wide gains.** The Kissimmee River restoration (Florida, USA) showed broad recovery following re-meandering, structure removal and floodplain reconnection: floodplain wetland area more than doubled within two years; natural channel-forming features re-established; and wading-bird densities met or exceeded project targets, alongside water-quality improvements (Bousquin & Colee, 2014; Cheek et al., 2014). On the Lower Danube, levee breaches, side-arm reconnections and floodplain forest restoration over two decades have demonstrated gains in native floodplain forest extent and condition (Ioana-Toroimac et al., 2024; Mansourian et al., 2019).

F19.   **Targeted wetland restoration enables recovery of specialist communities.** Across Europe and North America, rewetting of fens combined with nutrient-load reduction and restoration of groundwater flows has returned characteristic plant communities and improved habitat quality (Lamers et al., 2014) improving fish, macroinvertebrate and macrophyte indices (Kail et al., 2015). Removing invasive predators can rapidly restore native biota—as in South Africa's Rondegat River, where alien bass eradication was followed by rapid macroinvertebrate recovery and re-establishment of endemic fishes (Bellingan et al., 2019; Weyl et al., 2016). In high-Andean

páramo peatlands, canal blocking to raise water tables coupled with grazing exclusion has promoted rapid recovery of peat-forming vegetation and renewed use by specialist fauna, (Brück et al., 2023; Joslin, 2021; Thompson et al., 2021). At Baikka Beel, Bangladesh, a combination of fish refuges, habitat protection/vegetation recovery, community co-management and gear restrictions produced local biodiversity gains (waterbirds and native fishes) and spillover benefits (Winrock International, 2007; Thompson, 2008).

3.8.3   Case study – Kissimmee River Restoration, Florida, USA

The Kissimmee River in south-central Florida was channelized for flood control between 1962 and 1972, converting a 167 km meandering river into a 90 km drainage canal about 9 m deep and 75 m wide (Toth, 2002). Levees and water-control structures severed connections to the floodplain and created five near-stagnant pools (Koebel, 1995; Whalen et al., 2002). Channelization led to a build-up of soft organic sediments on the riverbed and halted the build up of sand bars on the inside of bends—features that help sustain a dynamic, meandering channel (Anderson, 2014).

Beginning in 1999 (construction completed July 2021), works aimed to re-establish up to 70 km of river channel, remove two water-control structures, restore the riparian zone, and reconnect up to 80 km² of floodplain wetlands (Whalen et al., 2002; Koebel & Bousquin, 2014a; 2014b). Phase I (completed February 2001) demolished one structure, excavated two new channel sections, restored flow to 23 km of channel, and seasonally re-inundated about 2,900 ha of floodplain (Whalen et al., 2002; Koebel & Bousquin, 2014a; 2014b).

A structured program tracked ~60 performance measures against pre-channelization benchmarks, spanning hydrology, channel form, water quality, wetland vegetation, the aquatic food web (phytoplankton, periphyton, invertebrates, herpetofauna), and fish and wildlife (Whalen et al., 2002).

Floodplain wetland plant communities more than doubled in area within two years of Phase I and by 2008 had nearly returned to pre-channelization extent (Spencer & Bousquin, 2014). Wading-bird densities in restored reaches met or exceeded the restoration expectation during post-construction monitoring (Cheek et al., 2014). Programme reporting documented fish-community and water-quality gains: largemouth bass and sunfishes increased from 38% to 68% of the assemblage and dissolved oxygen rose up to six-fold; ducks and eight shorebird species returned to the river–floodplain system (US Army Corps of Engineers, n.d.; South Florida Water Management District, n.d.).

3.8.4   Case study – East Dongting Lake hydrological management (China)

East Dongting Lake is a middle-Yangtze floodplain lake where prior hydrological alterations and habitat change had reduced the quality of wintering habitat for migratory waterbirds. Within protected units, management combined targeted water-level regimes and habitat works to maintain open water and variable depths across the winter period. Standardised winter surveys compared restored/managed units with unrestored controls across nine winters (2012–2020). Restored/managed units consistently supported higher waterbird species richness, density and diversity than unrestored controls, with gains observed across feeding guilds and linked to improved habitat availability under managed water levels (He et al., 2021; Zhang et al., 2021).

The East Dongting Lake restoration demonstrates that targeted hydrological management within floodplain-lake protected areas can deliver measurable, statistically robust increases in waterbird diversity over nearly a decade.

4   Freshwater restoration and trade-offs

4.1   Overview

Public policy decisions inherently involve trade-offs between competing interests and balancing the nature and quantum of the costs and benefits arising from those decisions, including how benefits and costs are shared across the community. This applies to most areas of public policy, including water resources management and environmental protection (Pegram et al., 2013). It equally applies to freshwater restoration.

Economic assessments consistently find that freshwater restoration delivers a net economic benefit (Brouwer & Sheremet, 2017). However, the benefits can come with trade-offs between competing objectives and unintended negative impacts. Decision-makers must navigate conflicts between different benefits (e.g. water supply vs. biodiversity), address trade-offs between stakeholder groups, mitigate any socio-economic disbenefits, and evaluate short-term losses against long-term gains.

4.2   Trade-offs between benefits

A restoration project that aims to enhance one service or value may impair another. For example:

- Reforestation and wetland restoration can improve carbon storage, soil retention, and habitat quality, but may reduce water yield available for human use (Liu et al., 2020b; Mu et al., 2022).
- Restoring natural floodplains or reconnecting rivers with wetlands can improve carbon sequestration and enhance flood storage, biodiversity and ecosystem health but often requires converting farmland or restricting development in flood-prone areas (Schwerk et al., 2025).
- Construction of check dams to improve aquifer recharge may reduce longitudinal connectivity within the watercourse (Bai et al., 2021).
- Redirecting or reallocating water to environmental flows (and related purposes) may result in increased fisheries catch, improved ecological outcomes, or more secure downstream urban water supplies, but mean less water for farms, potentially impacting economic productivity, requiring investments in efficiency and/or resulting in significant social impacts (Downham, 2024).
- Restoration projects may result in short-term increases in nutrient releases due to sediment disturbance during restoration (Peacock et al., 2023; Schwerk et al., 2025).

Further, freshwater restoration can impose uneven costs on certain communities and economic sectors. Affected groups may include local residents who are displaced, resource users whose activities are curtailed, or industries facing new restrictions. Trade-offs may include reduced availability of land or water for agriculture or changed water infrastructure regimes that affect other users (Schwerk et al., 2025). Restoration that seeks to return an ecosystem to its original state can provoke opposition if it diminishes services people have come to depend on; one of the main barriers to peatland rewetting has been the socio-economic impact on farmers and foresters who rely on drained peatlands for income (Temmink et al., 2023; 2024).

4.3   Time-related aspects of trade-offs

Many restoration trade-offs have a temporal element: short-term costs or losses are traded for long-term gains. Time-related trade-offs arise primarily due to ecological and ecosystem service lags associated with restoration projects. Restoring ecosystems often involves upfront costs, including financial investments and temporary disruptions, that may exceed the immediate benefits.

Ecosystem functions may take time to recover after intervention, and, in some cases, conditions can worsen briefly before improving. Re-wetting dried peatlands or reflooding a wetland can cause a short-term spike in methane emissions, even though the long-term outcome is a substantial reduction in carbon dioxide emissions and net climate benefit (Schuster et al., 2024; Hashemi et al., 2025). Removing a dam can release trapped sediment and can degrade water quality for a period (Rubin et al., 2017). Newly planted forests might suppress water yield until they mature (van Dijk & Keenan, 2007).

Table 6 provides a summary of the key trade-offs related to freshwater restoration identified by the literature review.

Table 6. Trade-offs arising from freshwater restoration

Trade-off	Description	Example	Sources
Ecological and biodiversity trade-offs	Restoring one ecosystem attribute negatively impacts other aspects of biodiversity, habitat complexity, or ecological integrity.	Improving riverine habitat with a focus on fish delivers a habitat that results in lower diversity of invertebrates.	Palmer et al. (2010), Perkins et al. (2021), Vaughan et al. (2012), Verberk et al. (2010), Zhao et al. (2023)
Invasive species risks	Restoration inadvertently increases the risk of the spread or establishment of invasive species (e.g. in the case of restoration to improve connectivity).	Restoration of a wetland provides conditions conducive to establishment of invasive plants.	Eckert et al. (2019), Fuller et al. (2018), de Leeuwen et al. (2024), Dolan et al. (2025)
Land-use/agricultural conflicts	Restoration affects existing agricultural land uses, including loss of productive land or changes to farming practices.	Water relocated for environmental flows reducing irrigation potential; agricultural land reclaimed to reestablish wetlands.	Fan et al. (2013), Hansen et al. (2018), Robledano et al. (2010), Schwerk et al. (2025)
Methane emissions	Restoration results in increased emissions of methane.	Rewetting wetlands to achieve improved carbon sequestration may result in increased methane emissions in the short-term.	Alderson et al. (2019), Brown et al. (2016), Page et al. (2009), Wilson et al. (2022), Schuster et al. (2024), Hashemi et al. (2025)
Pollution, sediment and nutrient mobilization and salinity impacts	Restoration causes temporary or ongoing mobilization of nutrients or pollutants (e.g., phosphorus, nitrogen), erosion or increased sedimentation, or salinity impacts.	Restored wetlands continue to release 'legacy' phosphorus, undermining restoration/water quality gains.	Fischer et al. (2021), Florsheim et al. (2013), Peacock et al. (2023), Raulings et al. (2011), Remiszewski et al. (2024), Sharpley et al. (2013), Stimson et al.

Trade-off	Description	Example	Sources
			(2017), Wilcock et al. (2013)
Temporary disturbances	Short-term negative impacts or disturbances caused by restoration activities, such as increased turbidity, sediment disruption, or physical habitat disturbance.	Increased turbidity or physical habitat disturbance as a result of reprofiling the watercourse.	Flitcroft et al. (2022), Howson et al. (2010), Kupilas et al. (2020), Suir et al. (2025), van Leeuwen et al. (2021)
Water management objectives	Conflicts between restoration goals and existing water management practices, including irrigation, hydropower, navigation, and flood protection.	Reallocation of water resources for environmental flow purposes reduces water available for irrigation.	Loflen et al. (2016), Steinman et al. (2022), Schwerk et al. (2025)

4.4   Managing trade-offs

The review identified several strategies for managing trade-offs associated with freshwater restoration. These include:

- **Early and effective stakeholder engagement**. Restoration planning should involve stakeholders early, assess who gains and who loses from proposed actions, and incorporate measures like livelihood restoration programs, retraining, or revenue-sharing to offset disbenefits. Such measures address fairness and can improve the long-term viability of restoration by securing local buy-in (Palmer et al., 2010).
- **Balancing the long-range vision with short-term support measures**. This could include coupling restoration initiatives with transition assistance, education, and incentive programs to compensate those impacted in the short-term by the restoration measures (Hein et al., 2006).
- **Understanding the timing of costs and benefits**. This is crucial for policymakers and communities to make informed decisions (Keeler et al., 2012).
- **Recognizing that different time horizons matter to different stakeholders**. For example, local communities may prioritize near-term livelihoods, while government may be focussed on ensuring enduring resilience/sustainability and ecosystem services (Olander et al., 2018).
- **Adopting a multi-benefit focus**. This reduces risks associated with a pursuing single-focus restorations (e.g. maximizing one species or service) which can inadvertently create disbenefits elsewhere (Kaiser et al., 2020).

5   Conclusions

5.1   Societal benefits of freshwater restoration

Global evidence from this review indicates that large-scale freshwater restoration can deliver wide-ranging ecological, hydrological, and social benefits. Across diverse regions and ecosystem types, interventions such as river re-meandering, floodplain reconnection, wetland rewetting, and dam removal have demonstrated measurable societal benefits (Table 7).

Hydrologically, restoration enhances water supply by increasing infiltration and baseflows, which boosts groundwater recharge and dry season flows. Wetland and riparian restoration also improve water quality by filtering sediments and nutrients, reducing treatment costs and health risks from polluted water. Reconnected floodplains and river channels attenuate flood peaks and extent, often reducing flood damage and risk more cost-effectively than traditional flood control infrastructure. In terms of climate regulation, peatland rewetting and wetland restoration have been shown to curb greenhouse gas emissions by turning degraded carbon sources into net carbon sinks. Many restoration sites thus contribute to carbon sequestration and climate adaptation goals. Importantly, many of these projects serve as cost-effective alternatives or complements to grey infrastructure, especially for flood mitigation and water treatment, while providing co-benefits that engineered approaches alone cannot.

Ecologically, interventions have led to notable biodiversity gains: revitalized flow regimes and habitat complexity drive the recovery of native fish, waterbirds, and other biota across multiple trophic levels. Examples include rapid rebounds of migratory fish once barriers are removed and the return of specialist wetland vegetation and wildlife after rewetting. Restored areas also generate provisioning and cultural benefits: increased fish stocks and local incomes through community co-management, new recreation and tourism opportunities, and strengthened cultural connections to rivers.

The effectiveness of restoration interventions is influenced by context and proactive management of trade-offs. The review highlights that while long-term benefits are significant, projects often face short-term costs or challenges that need to be navigated. Key factors for successful outcomes include early and inclusive stakeholder engagement and fair benefit-sharing to ensure local buy-in. Adopting a multi-benefit planning approach, informed by science and local or indigenous knowledge, is also critical. Furthermore, recognizing the temporal dimension of outcomes, and that ecological recovery and service improvements may take years or decades, helps set realistic expectations and maintains support.

In summary, freshwater restoration has proven potential to provide substantial benefits at scale, but its success depends on evidence-based design, adaptive management, and addressing social and environmental trade-offs. The diverse experiences set out in this report underscore that when guided by sound science and stakeholder collaboration, restoration can be a powerful tool for rebuilding freshwater resilience and delivering multifaceted benefits in a changing world.

Table 7. Benefits attributable to freshwater restoration. Supporting evidence for each statement (F1-F19) is set out in detail in section 3 and in Appendices B-H.

Benefit type	Benefits attributable to freshwater restoration
Water supply	F1. **Increased water yield and more reliable baseflows**: Freshwater ecosystem restoration can augment water yields for human use. Increased infiltration into soils and aquifers because of restoration enhances soil moisture and improves baseflows. F2. **Enhanced groundwater recharge**: By increasing soil infiltration, freshwater ecosystem restoration increases aquifer recharge.
Pollution reduction	F3. **Improved water quality**: Wetlands and riparian buffers trap sediments, take up excess nutrient pollution, and break down contaminants before water reaches rivers or aquifers, resulting in improvements in key water quality parameters. F4. **Reduced water treatment costs**: Restoration can significantly reduce the need for expensive water treatment infrastructure and ongoing water treatment costs. F5. **Improved drinking water and public health outcomes**: Restoration can reduce turbidity, pathogens, and nutrient runoff, lowering the risk of contaminated drinking water.
Flood risk reduction	F6. **Attenuation of flood peaks and cost-effective flood management**: Reconnecting rivers to floodplains and restoring wetlands markedly reduces flood surges. Reducing flood risks via nature-based solutions is often more cost-efficient than hard infrastructure. F7. **Reduced flood damages**: By absorbing excess water and reducing flood peaks, restored floodplains and wetlands significantly reduce the damage caused by floods.
Carbon sequestration	F8. **Rewetting of peatlands is a favoured wetland restoration measure to achieve carbon storage and GHG benefits.** This is because: (i) they have a high natural carbon storage capacity, (ii) large areas of peatland have long been subjected to draining, becoming ongoing sources of carbon to the atmosphere, and (iii) rewetting to increase carbon storage capacity and prevent further carbon loss is relatively straightforward. F9. **Emissions from degraded wetlands could be substantially reduced through restoration.** Restoration across 355–484 million hectares of wetlands could sequester 3—9% of current global carbon emissions.
Food security	F10. **Restoration through community co-management and establishing fish refuges rapidly rebuilds fish stocks and increases fisher incomes.** This has knock-on benefits, including raised fish consumption and improved food security among poorer households.

	F11. **Reconnecting rivers (dam removals and fish passage) restores migratory fish runs that underpin regional fisheries.** Removal of dams and establishing fish passages has been shown to improve migration, spawning conditions, and overall fish numbers.

F12. **Restored freshwater wetlands and reconnected floodplains can deliver quantified food provisioning (as well as fibre and energy) that buffers household food security.** Restoration has been shown in increase populations of fish species and waterbirds, as well as the extent of wetland vegetation, that are key food sources for local communities and/or contribute to household income. |
| **Cultural and social benefits** | **F13.** **Increased outdoor recreation and tourism**: Restoring rivers has been shown to increase recreation opportunities and usage, including more people swimming, paddling, boating, fishing, and viewing wildlife, as well as bringing economic benefits to communities and local businesses.

F14. **Strengthened cultural and spiritual connections**: River restoration, such as improving flows or removing barriers, can restore access to culturally important species and sites.

F15. **Improved aesthetic quality and community well-being**: Restoration can transform waterways into attractive public spaces, enhancing recreational spaces, improving human mental and physical wellbeing, improving community pride, and reconnecting people with their local environment. |
| **Biodiversity and supporting services** | **F16.** **Hydrological reconnection and managed water regimes drive multi-taxon recovery.** Where floodplains are reconnected and water levels managed to mimic seasonal variation, biodiversity responses are strong and consistent.

F17. **Removing barriers restores native fish assemblages and aquatic communities.** Connectivity restoration has yielded rapid fish responses in a range of different settings.

F18. **Large-scale river and floodplain reconnection delivers ecosystem-wide gains.** Benefits include increases in floodplain wetland and floodplain forest extent and condition as well as increases in fish assemblage and bird densities.

F19. **Targeted wetland restoration enables recovery of specialist communities.** Measures including rewetting, nutrient-load reduction, restoration of groundwater inputs, re-naturalising channel morphology and habitat complexity, and removing invasive predators have returned characteristic plant communities, improved habitat quality, and led to significant improvements in fish, macroinvertebrate and macrophyte indices. |

5.2   Restoration, resilience and co-benefits

In addition to providing the benefits described in Table 7, the review supports the view that freshwater ecosystem restoration enhances climate resilience by reinstating natural processes that buffer societies against the increasing frequency and intensity of floods, droughts, and other climate-driven extremes.

Restored floodplains, wetlands, and riparian zones slow runoff, store floodwaters, and recharge aquifers, providing resilience to both hydrological variability and long-term climatic shifts. By increasing baseflows and groundwater recharge, restoration secures water availability during dry seasons, sustaining ecosystems and human needs, including under prolonged drought conditions (Acreman & Holden, 2013).

Case studies illustrate these benefits. In South Africa, clearing invasive alien vegetation under the Working for Water program substantially increased annual water yield, improving water security (Marais & Wannenburgh, 2008). In Ethiopia, rehabilitated catchments maintained year-round baseflow where streams in degraded catchments would otherwise have run dry. This has reduced agricultural and socioeconomic drought impacts in those areas, including resulting in fewer water use conflicts between the communities along the river courses (Meaza et al., 2022).

In the Yangtze Basin (China), reconnecting nearly 3,000 km² of floodplain wetlands added 8 billion m³ of floodwater retention capacity, reducing the likelihood of levee overtopping during extreme events and safeguarding millions of people from climate-amplified flood risk (Pittock & Xu, 2011). Similarly, the Netherlands' Room for the River program restored floodplain connectivity along major rivers, thereby increasing resilience to projected climate-driven increases in peak discharges (Klijn et al., 2013; Van Alphen, 2019).

Freshwater restoration also strengthens food security in the face of climate change. Restoring environmental flows and reconnecting rivers with their floodplains has been shown to sustain inland fisheries that provide critical food and livelihoods, particularly under increasing climate variability (Arthington et al., 2018; Allan et al., 2005). In Bangladesh's Meghna Basin, community-managed fish refuges buffered local livelihoods against shifting monsoon patterns, nearly doubling household incomes within four years (Sayer et al., 2025).

5.3   Potential contribution of restoration to international environmental agreements

The evidence synthesis, as set out in section 3, has identified that restoration of freshwater ecosystems has the potential to contribute towards the goals of a wide range of international environmental agreements. Table 8 sets out the potential contribution of restoration towards goals and targets under different international environmental agreements, together with the supporting findings.

Table 8. Contribution of freshwater restoration towards international environmental agreements. Supporting findings are references to the findings set out in section 3.

Agreement	Relevant goal/target	Restoration benefit	Supporting findings
CBD	2030 Global Biodiversity Framework – Restore 30% of degraded inland water ecosystems	Biodiversity & supporting ecosystem services	F16, F17, F17, F19
	Ensure sustainable use of biodiversity (maintain ecosystem services)	Water supply, pollution reduction & flood risk reduction	F1, F3, F6

	Paris Agreement – Mitigation (reduce GHG emissions)	Carbon storage and GHG fluxes	F8, F9
UNFCCC	Paris Agreement – Adaptation (enhance climate resilience)	Flood risk reduction	F7
		Water supply	F1, F2
UNCCD	Combat desertification and drought (Land Degradation Neutrality)	Water supply	F1, F2
SDG 6	Target 6.3: Improve water quality Target 6.4: Ensure sustainable water withdrawals Target 6.6: Protect and restore water-related ecosystems	Water supply & pollution reduction	F1, F2, F3
SDG 15	Target 15.1: Restore inland freshwater ecosystems & services	Biodiversity & supporting ecosystem services	F17, F19
SDG 2	Zero Hunger – improve food security and nutrition	Food security	F10, F11, F12
SDG 13	Climate Action – strengthen resilience to climate impacts	Water supply & flood risk reduction	F1, F2, F7
Sendai	2030 goal to substantially reduce disaster losses	Flood risk reduction	F7
	2030 goal to substantially reduce disaster losses	Water supply	F1, F2
Ramsar	Wise use of wetlands – maintain ecological character	Biodiversity and supporting ecosystem services	F17, F19

5.4   Data and research gaps

The review process, while based on a relatively rapid assessment, has considered a wide range of material. While the review identified substantial evidence of the societal benefits of freshwater restoration, it also identified data and research gaps:

- There are many studies that consider the biophysical implications of freshwater restoration. Similarly, there are a large number of studies that have assessed the societal benefits from healthy freshwater systems. There are however far fewer studies that consider both the biophysical changes achieved through restoration **and** the implications of those changes for people and society. This often requires extrapolation of the biophysical outcomes from freshwater restoration to infer societal benefits.

- In many of the articles reviewed, while studies may identify societal benefits from restoration, these benefits are often not quantified. In many instances it is assumed or inferred that there are benefits to society, and this indeed is likely to be the case: improved water quality, or increases in fish stocks are likely to benefit the communities that rely on those resources, but those benefits are often not quantified.

- There has been substantial research on the role of freshwater systems in carbon sequestration and GHG fluxes, including both modelling and on-ground studies. However, the studies present a wide variety of results, depending on method adopted (particularly in the case of global studies) or the location (for on-ground studies). There would be benefit in further work to rationalise these studies as a basis for recommendations on where and how freshwater restoration can best achieve positive carbon/GHG outcomes.

- Many studies are based on modelling studies that assess hypothetical or potential restoration projects. While these are informative, there are fewer studies that present evidence based on monitoring in response to actual works on the ground.
- More broadly, where monitoring data exists, this is typically for relatively short periods (1-2 years). Studies that rely on long-term monitoring are limited in number.
- There is generally a larger evidence base in the literature for studies undertaken in Europe and North America.

6 References

Abbott, K.A. (2023). River restoration through dam removal: examining ecological responses to small dam removals across Massachusetts. University of Massachusetts Amherst (PhD dissertation). https://doi.org/10.7275/35952943.

Abell, J.M., Pingram, M.A., Özkundakci, D., David, B.O., Scarsbrook, M., Wilding, T., Williams, A., Noble, M., Brasington, J. & Perrie, A. (2022). Large floodplain river restoration in New Zealand: synthesis and critical evaluation to inform restoration planning and research. *Regional Environmental Change*, **23**(18). https://doi.org/10.1007/s10113-022-01995-z.

Acreman, M. & Holden, J. (2013). How wetlands affect floods. *Wetlands*, 33(5), 773–786. https://doi.org/10.1007/s13157-013-0473-2

Albert, J., Destouni, G., Duke-Sylvester, S., Magurran, A., Oberdorff, T., Reis, R., Winemiller, K. & Ripple, W. (2021). Scientists' warning to humanity on the freshwater biodiversity crisis. *Ambio*., 50(1), 85-94. https://doi.org/10.1007/s13280-020-01318-8.

Allan, J. D., Abell, R., Hogan, Z., Revenga, C., Taylor, B. W., Welcomme, R. L., & Winemiller, K. (2005). Overfishing of inland waters. BioScience, 55(12), 1041–1051. https://doi.org/10.1641/0006-3568(2005)055[1041:OOIW]2.0.CO;2

Anderson, D.H. 2014. Geomorphic responses to interim hydrology following Phase I of the Kissimmee River Restoration Project, Florida. *Restoration Ecology*, 22(3), 367-375. https://doi.org/10.1111/rec.12061.

Arias-Ortiz, A., Oikawa, P.Y., Carlin, J., Masqué, P., Shahan, J., Kanneg, S., Paytan, A., & Baldocchi, D.D. (2021). Tidal and nontidal marsh restoration: A trade-off between carbon sequestration, methane emissions, and soil accretion. *Journal of Geophysical Research: Biogeosciences*, 126(12). https://doi.org/10.1029/2021JG006573.

Armstrong, L., Peralta, A., Krauss, K.W., Cormier, N., Moss, R.F., Soderholm, E., McCall, A., Pickens, C., & Ardón, M. (2022). Hydrologic restoration decreases greenhouse gas emissions from shrub bog peatlands in southeastern US. *Wetlands*, 42, 81. https://doi.org/10.1007/s13157-022-01605-y.

Aronson, J., Goodwin, N., Orlando, L., Eisenberg, C. & Cross, A.T. (2020). A world of possibilities: six restoration strategies to support the United Nation's Decade on Ecosystem Restoration. *Restoration Ecology*, 28(4), 730–736. https://doi.org/10.1111/rec.13170

Arthington, A.H., Kennen, J.G., Stein, E.D., & Webb, J.A. (2018). Recent advances in environmental flows science and water management – innovation in the Anthropocene. Freshwater Biology, 63(8), 1022–1034.

Arthur, R.I., Skerritt, D.J., Schuhbauer, A., Ebrahim, N., Friend, R.M., & Sumaila, U.R. (2023). Small-scale fisheries and local food systems: transformations, threats and opportunities. *Fish and Fisheries*, 23(1), 109-124. https://doi.org/10.1111/faf.12602.

Asian Development Bank (2022). *Reviving the Springs of Nepal's Mountain Eco-Regions*. Development Asia case study. Manila: ADB. https://development.asia/case-study/reviving-springs-nepals-mountain-eco-regions

Atlantic Salmon Federation (2024). Penobscot River Fish Passage Update (Oct 20, 2024). ASF Update (with Maine Department of Marine Resources, Sea Run Fisheries and Habitat. Provisional data). Retrieved from https://www.asf.ca/wp-content/uploads/2024/10/Penobscot-River-Update-10202024.pdf.

Audet, J., Zak, D., Bidstrup, J. & Christian Hoffmann, C. (2020). Nitrogen and phosphorus retention in Danish restored wetlands. *Ambio* 49, 324–336. https://doi.org/10.1007/s13280-019-01181-2

Aylward, B., Bandyopadhyay, J., Belausteguigotia, J.-C., Börkey, P., Cassar, A., Meadors, L., Saade, L., Siebentritt, M., Stein, R., Tognetti, S. & Tortajada, C. (2005). Freshwater ecosystem services. In K. Chopra, R. Leemans, P. Kumar, & H. Simons (Eds.), *Ecosystems and human well-being: Policy responses* (pp. 213–256). Island Press.

Bai, L., Jiao, J., Wang, N., & Chen, Y. (2021). Structural connectivity of sediment affected by check dams in Loess Hilly-Gully Region, China. *Water*, 13(19), Article 2644. https://doi.org/10.3390/w13192644

Baird, I.G., & Flaherty, M.S. (2005). Mekong river Fish Conservation Zones in Southern Laos: assessing effectiveness using local ecological knowledge. *Environmental Management*, 36(3), 439–454.

Baker, C.F., Franklin, P.A., & van Schravendijk-Goodman, C. (2014). Restoration of īnanga (whitebait) spawning habitat in the lower Waikato River: progress report for 2013/14, NIWA Client Report HAM2014-115, 53 pp.

Baragangina Resource Management Organization (RMO) (2017). Baikka Beel Sanctuary, Hail Haor. Brochure, April. Retrieved from https://nishorgo.org/wp-content/uploads/2017/04/5-2-1-MACH-Baikka-Beel-Sanctuary-English-Brochure.pdf.

Basak, S. M., Hossain, M. S., Tusznio, J. & Grodzińska-Jurczak, M. (2021). Social benefits of river restoration from ecosystem services perspective: A systematic review. *Environmental Science & Policy*, 124, 90–100. https://doi.org/10.1016/j.envsci.2021.06.005.

Bayliss, P. & Ligtermoet, E. (2018). Seasonal habitats, decadal trends in abundance and cultural values of magpie geese (*Anseranus semipalmata*) on coastal floodplains in the Kakadu Region, northern Australia. *Marine and Freshwater Research*, **69**, 1079–1091. https://doi.org/10.1071/MF16118_AC.

Bell, D., Johnston, C. & Jones, A. (2020). *Budj Bim Cultural Landscape – UNESCO World Heritage Site nomination document*. Gunditj Mirring Traditional Owners Aboriginal Corporation. Retrieved from UNESCO World Heritage Centre: https://whc.unesco.org/en/list/1577

Bellingan, T.A., Hugo, S., Woodford, D.J., Gouws, J., Villet, M.H., & Weyl, O.L.F. (2019). Rapid recovery of macroinvertebrates in a South African stream treated with rotenone. *Hydrobiologia*, 834, 1–11. https://doi.org/10.1007/s10750-019-3885-z.

Bernal, B. & Mitsch, W.J. (2011). Comparing carbon sequestration in temperate freshwater wetland communities. *Global Change Biology*, 18(5), 1636-1647. https://doi.org/10.1111/j.1365-2486.2011.02619.x.

Bianchi, A., Larmola, T., Kekkonen, H., Saarnio, S., & Lång, K. (2021). Review of Greenhouse Gas Emissions from Rewetted Agricultural Soils. *Wetlands*, 41, 108. https://doi.org/10.1007/s13157-021-01507-5.

Bousquin, S.G., & Colee, J. 2014. Interim Responses of Littoral River Channel Vegetation to Reestablished Flow after Phase I of the Kissimmee River Restoration Project. *Restoration Ecology*, 22(3), 388-396. https://doi.org/10.1111/rec.12068

Bousquin, S.G., Anderson, D.H., Colangelo, D.J., Glenn III, J.L., Koebel Jr. J.W. & Williams, G.E. 2012. Phase I of the Kissimmee River Restoration Project: Initial River Channel Responses. In *Proceedings World Environmental and Water Resources Congress 2007: Restoring Our Natural Habitat*, Tampa, Florida, May 15-19, 2007, American Society of Civil Engineers, Reston, VA. https://doi.org/10.1061/40927(243)629.

Brandis, K., Stewart, J., & Francis, R. (2023). Gwydir Wetlands: drone monitoring of aggregating breeding waterbirds 2022–23. Final report to the Commonwealth Environmental Water Office. Centre for Ecosystem Science, UNSW. https://www.dcceew.gov.au/sites/default/files/documents/gwydir-wetlands-drone-monitoring-aggregating-breeding-waterbirds-2022-23.pdf.

Bregnballe, T., Amstrup, O., & Bak, M. (2009). Responses of autumn staging waterbirds to wetland restoration and water levels in a Danish river delta. *Wildfowl (Special Issue)*, 2, 143–157. https://wildfowl.wwt.org.uk/index.php/wildfowl/article/view/1349.

Bregnballe, T., Amstrup, O., Holm, T.E., Clausen, P., & Fox, A.D. (2014). Skjern River Valley, Northern Europe's most expensive wetland restoration project: benefits to breeding waterbirds. *Ornis Fennica*, 91(4), 231–243. https://ornisfennica.journal.fi/article/view/133860.

Brenkman, S.J., Peters, R.J., Tabor, R.A., Geffre, J.J., & Sutton, K.T. (2019). Rapid Recolonization and Life History Responses of Bull Trout Following Dam Removal in Washington's Elwha River. *North American Journal of Fisheries Management*, 39(3), 560–573. https://doi.org/10.1002/nafm.10291.

Brouwer, R. & Sheremet, O. (2017). The economic value of river restoration. *Water Resources and Economics,* 17, Article 1–8. https://doi.org/10.1016/j.wre.2017.02.005

Brück, S.A., Medina Torres, B.D., & Teixeira de Moraes Polizeli, M.L. (2023). The Ecuadorian paramo in danger: What we know and what might be learned from northern wetlands. *Global Ecology and Conservation*, 47, e02639. https://doi.org/10.1016/j.gecco.2023.e02639.

Bryan, B.A., Kandulu, J.M., Deere, D.A., White, M., Frizenschaf, J., & Crossman, N.D. (2009). Adaptive management for mitigating *Cryptosporidium* risk in source water: A case study in an agricultural catchment in South Australia. *Journal of Environmental Management*, 90(10), 3122–3134. https://doi.org/10.1016/j.jenvman.2009.05.014

Campos-Silva, J.V., & Peres, C.A. 2016. Community-based management induces rapid recovery of a high value tropical freshwater fishery. *Scientific Reports*, 34745. https//doi.org/10.1038/srep34745

Carnell, P., Windecker, S., Brenker, M., Baldock, J. Masqué, P., Brunt, K., & Macreadie, P. (2018). Carbon stocks, sequestration, and emissions of wetlands in south eastern Australia. *Global Change Biology*, 24(2). https://doi.org/10.1111/gcb.14319.

Carnell, P., Windecker, S., Brenker, M., Yukate, B., Johnson, K., & Macreadie, P. (2016). Carbon sequestration by Victorian inland wetlands. Blue Carbon Lab, Centre for Integrative Ecology, School of Life and Environmental Sciences, Deakin University, Victoria, Australia. Goulburn Broken CMA. Retrieved from

https://www.gbcma.vic.gov.au/downloads/climatechange/carbonsequestrationbyinlandvictorianwe
tlands_final.pdf.

Carpenter, S.R., Stanley, E.H. & Vander Zanden, M.J. (2011). State of the world's freshwater
ecosystems: Physical, chemical, and biological changes. *Annual Review of Environment and
Resources*, 36(1), 75–99. https://doi.org/10.1146/annurev-environ-021810-094524

Center for Natural Resource Studies (CNRS) (2023). Baikka Beel Permanent Wetland Sanctuary.
CNRS, Dhaka, Bangladesh, June. https://cnrs.org.bd/2023/06/04/baikka-beel-permanent-wetland-
sanctuary/.

Cheek, M.D., Colangelo, D.J., & Bousquin, S.G. (2014). Interim response of wading birds
(*Pelecaniformes* and *Ciconiiformes*) and waterfowl (*Anseriformes*) to the Kissimmee River
Restoration Project. *Restoration Ecology*, 22(3), 418–427. https://doi.org/10.1111/rec.12059.

Chen, Y., Guo, W., Ngo, H.H., Wei, W., Ding, A., Ni, B., Hoang, N.B. & Zhang, H. (2024). Ways to
mitigate greenhouse gas production from rice cultivation. *Journal of Environmental Management*,
368, 122139. https://doi.org/10.1016/j.jenvman.2024.122139.

Coates, D. (2023). Ecosystem restoration and inland fisheries in developing countries – opportunities
for the United Nations Decade on Ecosystem Restoration (2021–2030). *FAO Fisheries and
Aquaculture Circular No. C1231*. https://doi.org/10.4060/cc7082en.

Coates, D., Pert, P. L., Barron, J., Muthuri, C., Nguyen-Khoa, S., Boelee, E. & Jarvis, D. I. 2013. Water-
related ecosystem services and food security. In Boelee (Ed.), *Managing water and agroecosystems
for food security*, CAB International, Oxfordshire, UK, pp. 29-41.
https://doi.org/10.1079/9781780640884.0029.

Collier, K.J., Baker, C., David, B.O., Górski, K. & Pingram, M.A. (2017). Linking ecological science with
management outcomes on New Zealand's longest river. *River Research and Applications*, **35**(5), 476-
488. https://doi.org/10.1002/rra.3181.

Collins, A.M., Coughlin, D., Miller, J. & Kirk, S. 2015. *The Production of Quick Scoping Reviews and
Rapid Evidence Assessments: A How to Guide*. Department for Environment Food & Rural Affairs,
NERC Science of the Environment. December.
https://assets.publishing.service.gov.uk/media/5a7f3a76ed915d74e33f5206/Production_of_quick_s
coping_reviews_and_rapid_evidence_assessments.pdf

Convention on Biological Diversity. (2022). *Kunming–Montreal Global Biodiversity Framework*.
Convention on Biological Diversity. Secretariat of the Convention on Biological Diversity, Montreal.
https://www.cbd.int/gbf

Convention on Wetlands (2021). Global Wetland Outlook: Special Edition 2021. Secretariat of the
Convention on Wetlands, Gland, Switzerland. Retrieved from
https://www.ramsar.org/resources/publications/global-wetland-outlook.

Convention on Wetlands. (1971). *Convention on Wetlands of International Importance especially as
Waterfowl Habitat*. Ramsar 2/02/1971, UNESCO.
https://www.ramsar.org/sites/default/files/documents/library/current_convention_text_e.pdf

Convention on Wetlands. (2025). *Global Wetland Outlook 2025: Valuing, conserving, restoring and
financing wetlands*. Secretariat of the Convention on Wetlands. https://doi.org/10.69556/GWO-
2025-eng

Cowardin, L.M., Carter, V., Golet, F.C., & LaRoe, E.T. (1979). *Classification of wetlands and deepwater habitats of the United States* (FWS/OBS-79/31). U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services, December.

Cowdery, T.K., Christenson, C.A. & Ziegeweid, J.R. (2019). The hydrologic benefits of wetland and prairie restoration in western Minnesota—Lessons learned at the Glacial Ridge National Wildlife Refuge, 2002–15. *USGS Scientific Investigations Report 2019–5041*.

Dahm, C.N., Cummins, K.W., Valett, H.M. & Coleman, R L. 1995. An Ecosystem View of the Restoration of the Kissimmee River. *Restoration Ecology*, 3(3), 225-238, https://doi.org/10.1111/j.1526-100X.1995.tb00172.x.

Darusman, T., Murdiyaso, D. & Anas, I. (2023). Effect of rewetting degraded peatlands on carbon fluxes: a meta-analysis. *Mitigation and Adaptation Strategies for Global Change*, 28, 10. https://doi.org/10.1007/s11027-023-10046-9.

Dashora, Y., Dillon, P., Maheshwari, B., Soni, P., Mittal, H.K., Dashora, R. & Singh, P.K. (2018). A simple method using farmers' measurements applied to estimate check dam recharge in Rajasthan, India. *Sustainable Water Resources Management, 4*(2), 301–316. https://doi.org/10.1007/s40899-017-0158-5

de Jong, M., van Hal, O., Pijlman, J., van Eekeren, N. & Junginger, M. (2021). Feasibility of Typha cultivation for building materials and feed in rewetted peatlands. *Science of the Total Environment*, 792, 148161. https://doi.org/10.1016/j.scitotenv.2021.148161.

de Lacerda, L.D., Ward, R.D., Godoy, M.D.P., Meireles, A.J.A., Borges, R. & Ferreira, A.C. (2021). 20-Years cumulative impact from shrimp farming on mangroves of Northeast Brazil. *Frontiers in Forests and Global Change*, 4, Article 653096. https://doi.org/10.3389/ffgc.2021.653096

Deffner, J., & P. Haase. 2018. The societal relevance of river restoration. *Ecology and Society* 23(4):35. https://doi.org/10.5751/

Delaney R., Fukuda Y. & Saalfeld, K. (2009). Management Program for the Magpie Goose (*Anseranas semipalmata*) in the Northern Territory of Australia, 2009–2014. Northern Territory Department of Natural Resources, Environment, the Arts and Sport, Darwin. Retrieved from https://denr.nt.gov.au/__data/assets/pdf_file/0004/441526/Magpie-Goose-Management-Program-2009-2014.pdf.

Delwiche, K., Matthes, J.H., Arias-Ortiz, A., Knox, S.H., Oikawa, P., Sturtevant, C., Verfaillie, J., Szutu, D., Keenan, T.F., & Baldocchi, D. (2025). Dynamic methane emissions in a restored wetland: Decadal insights into uncertain climate outcomes and critical science needs. *Agricultural and Forest Meteorology*, 373. https://doi.org/10.1016/j.agrformet.2025.110735.

Department of Climate Change, Energy, the Environment and Water (DCCEEW). (2023). Reef Trust water quality achievements (Fact sheet). https://www.dcceew.gov.au/sites/default/files/documents/reef-trust-water-quality-achievements.pdf

Department of Forestry, Fisheries and the Environment (n.d.). Working for Water (WfW) Defined. Accessed 24 August 2025 at https://www.dffe.gov.za/ep_focusareas_wfw

Ding, C., Jiang, X., Wang, L., Fan, H., Chen, L., Hu, J., Wang, H., Chen, Y., Shi, X., Chen, H., Pan, B., Ding, L., Zhang, C. & He, D. (2019). Fish Assemblage Responses to a Low-head Dam Removal in the Lancang River. *Chinese Geographical Science*, 29, 26-36. https://doi.org/10.1007/s11769-018-0995-x.

Dixon, S. J., Sear, D. A., Odoni, N. A., Sykes, T. & Lane, S. N. (2016). The effects of river restoration on catchment scale flood risk and flood hydrology. *Earth Surface Processes and Landforms*, 41(7), 997–1008. https://doi.org/10.1002/esp.3919

Dolan, E. J., Soto, I., Dick, J. T. A., He, F. & Cuthbert, R. N. (2025). Riverine barrier removals could proliferate biological invasions. *Global Change Biology*, 31(3), Article e70093. https://doi.org/10.1111/gcb.70093

Dottori, F., Bianchi, A., Alfieri, L. & Feyen, L. (2023). Cost-effective adaptation strategies for flood risk under climate change in Europe. *Nature Climate Change,* 13(1), 75–82. https://doi.org/10.1038/s41558-022-01544-4

Downham, R., Walsh, J., Gupta, M., Galeano, D. & Hone, S. (2024). *The impacts of further water recovery in the southern Murray–Darling Basin.* (ABARES Research Report). Australian Bureau of Agricultural and Resource Economics and Sciences. https://doi.org/10.25814/611t-m537

Duda, J.J., Torgersen, C.E., Brenkman, S.J., Peters, R.J., Sutton, K.T., Connor, H.A., Kennedy, P., Corbett, S.C., Welty, E.Z., Geffre, A., Geffre, J., Crain, P., Shreffler, D., McMillan, J.R., McHenry, M. & Pess, G.R. (2021). Reconnecting the Elwha River: Spatial patterns of fish response to dam removal. *Frontiers in Ecology and Evolution*, 9, 765488. https://doi.org/10.3389/fevo.2021.765488.

Duda, J.J., Warrick, J.A. & Magirl, C.S. (Eds.). (2021). *Elwha River restoration: Lessons for river management and ecosystem recovery*. Island Press.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A-H., Soto, D., Stiassny, M.L.J. & Sullivan, C.A. (2006). Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews,* 81(2), 163–182. https://doi.org/10.1017/S1464793105006950

Dufour, S. & Piégay, H. (2009). From the myth of a lost paradise to targeted river restoration: Forget natural references and focus on human benefits. *River Research and Applications*, 25(5), 568–581. https://doi.org/10.1002/rra.1239

Duggan, K., Roberts, L., Beech, M., Robertson, H., Brady, M., Lake, M., Jones, K., Hutchinson, K. & Patterson, S. (2012). Whangamarino Outcomes Report 2007–2011 – Arawai Kākāriki Wetland Restoration Programme. Department of Conservation, Wellington, New Zealand. https://www.doc.govt.nz/Documents/conservation/land-and-freshwater/wetlands/whangamarino-outcomes-report.pdf.

EcoFutures Consulting Australia (2024). Influences of food resources on waterbird communities at the Hattah Lakes. Centre for Applied Water Science, University of Canberra. Mallee Catchment Management Authority. https://www.mdba.gov.au/sites/default/files/publications/influences-of-food-resources-on-waterbird-communities-at-the-hattah-lakes.pdf.

Emerton, L., Iyango L., Luwum, P. & Malinga, A. (1999). T*he Present Economic Value of Nakivubo Urban Wetland, Uganda*. Kampala, Uganda: IUCN-The World Conservation Union, Eastern Africa Regional Office, Nairobi, and National Wetlands Programme, Wetlands Inspectorate Division, Ministry of Water, Land and Environment, Kampala

European Environment Agency (EEA). (2016). *Rivers and lakes in European cities: Past and future challenges (EEA Report No 26/2016)*. European Environment Agency. Retrieved from https://www.eea.europa.eu/publications/rivers-and-lakes-in-cities

FAO Land & Water (2015). *Private sector engagement. Incentives for ecosystem services*. Incentives for Ecosystem Services in Agriculture (IES). Food and Agriculture Organization of the United Nations (FAO). https://www.fao.org/in-action/incentives-for-ecosystem-services/policy/private-sector-engagement/en/

Fetene, A., Yeshitela, K. & Desta, H. (2012). Approaches to Conservation and Sustainable Use of Biodiversity—A Review. *Nature & Science*, 10(12), 51–62. http://www.sciencepub.net/nature

Filoso, S., Bezerra, M.O., Weiss, K. C.B. & Palmer, M.A. (2017). *Impacts of forest restoration on water yield: A systematic review.* PLoS ONE, 12(8), e0183210. https://doi.org/10.1371/journal.pone.0183210

Fiorella, K.J., Bageant, E.R., Kim, M., Sean, V., Try, V., MacDonell, H.J., Baran, E., Kura, Y., Brooks, A.C., Barrett, C.B. & Thilsted, S.H. (2019). Analyzing drivers of fish biomass and biodiversity within community fish refuges in Cambodia. *Ecology and Society*, 24(3), 19. https://ecologyandsociety.org/vol24/iss3/.

Fluet-Chouinard, E., Stocker, B.D., Zhang, Z., Malhotra, A., Melton, J.R., Poulter, B., Kaplan, J.O., Klein Goldewijk, K., Siebert, S., Minayeva, T., Hugelius, G., Joosten, H., Barthelmes, A., Prigent, C., Aires, F., Hoyt, A.M., Davidson, N., Finlayson, C.M., Lehner, B., Jackson, R.B. & McIntyre, P.B. (2023). Extensive global wetland loss over the past three centuries. *Nature*, 614, 281–286. https://doi.org/10.1038/s41586-022-05572-6.

Freshwater Challenge (2023). About the Challenge. https://www.freshwaterchallenge.org/about-the-challenge

Funge-Smith, S.J. & Bennett, A. (2019). A fresh look at inland fisheries and their role in food security and livelihoods. *Fish and Fisheries*, 20(6), 1176–1195. https://doi.org/10.1111/faf.12403.

GHD (2023). Waterbird nesting and breeding activity – Hattah Lakes Icon Site – 2022/23. Report to Mallee CMA, Mildura, Victoria, June.

Gorham, E. (1991). Northern peatlands: Role in the carbon cycle and probable responses to climatic warming. *Ecological Applications*, 1, 182-195.

Grill, G., Lehner, B., Thieme, M., Geenen, B., Tickner, D., Antonelli, F., Babu, S., Borrelli, P., Cheng, L., Crochetiere, H., Ehalt Macedo, H., Filgueiras, R., Goichot, M., Higgins, J., Hogan, Z., Lip, B., McClain, M.E., Meng, J., Mulligan, M. … Zarfl, C. (2019). Mapping the world's free-flowing rivers. *Nature,* 569, 215–221. https://doi.org/10.1038/s41586-019-1111-9

Günther, A., Barthelmes, A., Huth, V., Joosten, H., Jurasinski, G., Koebsch, F. & Couwenberg, J. (2020). Prompt rewetting of drained peatlands reduces climate warming despite methane emissions. *Nature Communications*, 11, 1644. https://doi.org/10.1038/s41467-020-15499-z.

Gurung, T. B. (2007). Restoration of small lakes through cooperative management: A suitable strategy for poverty-laden areas in developing countries? *Lakes & Reservoirs: Research and Management*, 12(4), 237–246. https://doi.org/10.1111/j.1440-1770.2007.00341.x

Hamdi, N., Touihri, M. & Charfi, F. (2012). Diagnostic écologique du Parc National Ichkeul (Tunisie) après la construction des barrages: cas des oiseaux d'eau. *Revue d'Écologie (Terre et Vie)*, 67, 41–55.

Hansen, A.T., Dolph, C.L., Foufoula-Georgiou, E. & Finlay, J.C. (2018). Contribution of wetlands to nitrate removal at the watershed scale. *Nature Geoscience*, 11(2), 127–132. https://doi.org/10.1038/s41561-017-0056-6

Hashemi, M., Shaad, K., Griffey, V., Mohammed, I., Bolten, J., Bezerra, M. & Sprenkle-Hyppolite, S. (2025). Aspiration to action: Opportunities to align freshwater ecosystems with climate actions. *Nature Portfolio*, 25 May (under review). https://doi.org/10.21203/rs.3.rs-6626566/v1.

He, S.W. Han, Y.H. & Qin, X.D. (2025). Advances in accounting methodology of nitrous oxide emissions from the adipic acid industry. *Journal of Environmental Sciences*, 157, 615-632. https://doi.org/10.1016/j.jes.2024.03.014.

He, T., Ding, W., Cheng, X., Cai, Y., Zhang, Y., Xia, H., Wang, X., Zhang, J., Zhang, K. & Zhang, Q. (2024). Meta-analysis shows the impacts of ecological restoration on greenhouse gas emissions. *Nature Communications*, 15(1), 2668. https://doi/10.1038/s41467-024-46991-5.

He, X., Xie, Y., Zou, Y., Zhang, S. & Pan, B. (2021). Wetland restoration in the East Dongting Lake effectively increased waterbird diversity by improving habitat quality. *Global Ecology and Conservation*, 27, e01569. https://doi.org/10.1016/j.gecco.2021.e01569

Hein, L., van Koppen, K., de Groot, R.S. & van Ierland, E.C. (2006). Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics,* 57(2), 257–274.

Hein, T., Schwarz, U., Habersack, H., Nichersu, I., Preiner, S., Willby, N. & Weigelhofer, G. (2016). Current status and restoration options for floodplains along the Danube River. *Science of The Total Environment*, 543(A), 778-790. https://doi.org/10.1016/j.scitotenv.2015.09.073.

Heinrich-Böll-Stiftung, Succow Stiftung & BUND (2023). *Peatland Atlas 2023*. Heinrich-Böll-Stiftung. Retrieved from https://www.boell.de/en/2023/09/11/european-union-defending-diversity

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. https://doi.org/10.1016/j.agrformet.2019.01.017.

Hey, D.L., Montgomery, D.L., Urban, L.S., Prato, T., Forbes, A., Martell, M., Pollack, J., Steele, Y. & Zarwell, R. (2004). *Flood damage reduction in the upper Mississippi River Basin—An ecological alternative*. The Wetlands Initiative. Retrieved from http://www.wetlands-initiative.org

High Level Panel of Experts on Food Security and Nutrition (HLPE) (2014). Sustainable fisheries and aquaculture for food security and nutrition. HLPE of the Committee on World Food Security. FAO, Rome, June. Retrieved from https://openknowledge.fao.org/server/api/core/bitstreams/350d9c16-fce5-4f85-9324-a41939bb3b89/content?utm_source=chatgpt.com.

Hinshaw, S. & Wohl, E. (2023). Carbon sequestration potential of process-based river restoration. *River Research and Applications*, 39, 1812–1827.

Hoffmann, C.C., Zak, D., Kronvang, B., Kjaergaard, C., Carstensen, M.V. & Audet, J. (2020). An overview of nutrient transport mitigation measures for improvement of freshwater quality. *Water*, 12(12), 3371. https://doi.org/10.3390/w12123371

Hunt, L.J.H., Fair, J. & Odland, M. (2018). Meadow restoration increases baseflow and groundwater storage in the Sierra Nevada, California. *Journal of the American Water Resources Association (JAWRA),* 54(5), 1127–1136. https://doi.org/10.1111/1752-1688.12675

Huth, V., Günther, A., Bartel, A., Gutekunst, C., Heinze, S., Hofer, B., Jacobs, O., Koebsch, F., Rosinski, E., Tonn, C., Ullrich, K. & Jurasinski, G. (2022). The climate benefits of topsoil removal and *Sphagnum* introduction in raised bog restoration. *Restoration Ecology*, 30(1), e13490. https://doi.org/10.1111/rec.13490.

Ilstedt, U., Bargués Tobella, A., Bazié, H. R., Bayala, J., Verbeeten, E., Nyberg, G., Sanou, J., Benegas, L., Murdiyarso, D., Laudon, H., Sheil, D. & Malmer, A. (2016). Intermediate tree cover can maximize groundwater recharge in the seasonally dry tropics. *Scientific Reports,* 6, 21930.

Intergovernmental Panel on Climate Change (IPCC) (2014). *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands – Methodological guidance on lands with wet and drained soils, and constructed wetlands for wastewater treatment* (T. Hiraishi, T. Krug, K. Tanabe, N. Srivastava, J. Baasansuren, M. Fukuda, & T. G. Troxler, Eds.). IPCC.

Intergovernmental Panel on Climate Change (IPCC) (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

International Union for Conservation of Nature (IUCN) (2020). World Heritage Outlook 3: Ichkeul National Park. International Union for Conservation of Nature, Gland, Switzerland. https://worldheritageoutlook.iucn.org/node/983/pdf?year=2020.

International Union for Conservation of Nature IUCN (2021). Scaling-up flood-friendly livelihoods to strengthen climate change resilience in the Mekong Delta. IUCN, International Union for Conservation of Nature and Natural Resources, Gland, Switzerland. Retrieved from https://iucn.org/news/asia/202110/scaling-flood-friendly-livelihoods-strengthen-climate-change-resilience-mekong-delta.

Ioana-Toroimac, G., Panaitescu, M., Cîrstea, G. & Cîrmaciu, D. (2024). Restoring the Lower Danube River's wetlands: A short report on the hydrological effectiveness of completed projects. *Hydrological Research Letters*, 18, 1–8. https://doi.org/10.3178/hrl.18.1.

IPBES (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). S. Díaz, J. Settele, E.S. Brondízio, H.T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K.A. Brauman, S.H.M. Butchart, K.M.A. Chan, L.A. Garibaldi, K. Ichii, J. Liu, S.M. Subramanian, G.F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y.J. Shin, I.J. Visseren-Hamakers, K.J. Willis, & C.N. Zayas (Eds.). IPBES secretariat, Bonn, Germany. 56 pp. Retrieved from https://files.ipbes.net/ipbes-web-prod-public-files/inline/files/ipbes_global_assessment_report_summary_for_policymakers.pdf.

Isely, P., Isely, E. S., Hause, C. & Steinman, A. D. (2018). Socioeconomic benefits of habitat restoration: A case study of the Muskegon Lake Area of Concern. *Journal of Great Lakes Research*, 44(6), 1273–1284. https://doi.org/10.1016/j.jglr.2018.09.006

Jähnig, S.C., Lorenz, A.W., Hering, D., Antons, C., Sundermann, A., Jedicke, E. & Haase, P. (2012). River restoration success depends on the species pool of the immediate surroundings. *Ecological Applications*, 22(2), 513–521. https://doi.org/10.1890/11-0272.1

Jamu, D.M., Torell, E.C. & Chisale, E. (2023). Community-managed fish sanctuaries for freshwater fishery biodiversity conservation and productivity in Malawi. *Sustainability*, 15(5), 4414. https://doi.org/10.3390/su15054414.

Javaheri, A. & Babbar-Sebens, M. (2014). On comparison of peak flow reductions, flood inundation maps, and velocity maps in evaluating effects of restored wetlands on channel flooding. *Ecological Engineering,* 73, 132–145. https://doi.org/10.1016/j.ecoleng.2014.09.021

Johnson, K.A., Wing, O.E., Bates, P.D., Fargione, J., Kroeger, T., Larson, W.D., Sampson, C.C. & Smith, A.M. (2020). A benefit–cost analysis of floodplain land acquisition for US flood damage reduction. *Nature Sustainability,* 3(1), 56–62. https://doi.org/10.1038/s41893-019-0437-5

Jones, H.F.E. & Hamilton, D.P. (2014). Assessment of the Waikato River estuary and delta for whitebait habitat management: field survey, GIS modelling and hydrodynamic modelling, Environmental Research Institute Report No. 27, University of Waikato, Waikato Regional Council, 79 pp. Retrieved from https://researchcommons.waikato.ac.nz/handle/10289/12462.

Joosten, H., Tapio-Biström, M-L. & Tol, S. (eds.) (2012). *Peatlands - guidance for climate change mitigation through conservation, rehabilitation and sustainable use*. Second edition. Food and Agriculture Organization of the United Nations and Wetlands International.

Joslin, A. (2021). Intersections of Conservation, Cattle, and Culture in Ecuador's *Páramo* Grasslands. *Mountain Research and Development*, 41(4), R1-R7. https://doi.org/10.1659/MRD-JOURNAL-D-21-00015.1.

Kail, J., Brabec, K., Poppe, M. & Januschke, K. (2015). The effect of river restoration on fish, macroinvertebrates and aquatic macrophytes: a meta-analysis. *Aquatic Sciences*, 77(3), 673–683. https://doi.org/10.1007/s00027-015-0427-0.

Kaiser, N.N., Feld, C.K., Stoll, S. & Meyerhoff, J. (2020). Does river restoration increase ecosystem services? Evidence from a systematic review. *Ecosystem Services,* 46, 101206. https://doi.org/10.1016/j.ecoser.2020.101206

Kandel, T.P., Lærke, P.E., Hoffmann, C.C. & Elsgaard, L. (2019). Complete annual CO_2, CH_4, and N_2O balance of a temperate riparian wetland 12 years after rewetting. *Ecological Engineering*, 127, 527-535. https://doi.org/10.1016/j.ecoleng.2017.12.019.

Kang, M.-H. & Cervero, R. (2015). Assessment of an urban stream restoration project by cost–benefit analysis: Cheonggyecheon, Seoul, South Korea. *KSCE Journal of Civil Engineering, 19*(6), 1801–1811. https://doi.org/10.1007/s12205-013-0400-3

Kebede, M.M., Kumar, M., Mekonnen, M.M. & Clement, T.P. (2024). Enhancing groundwater recharge through nature-based solutions: Benefits and barriers. Hydrology, 11(11), 195. https://doi.org/10.3390/hydrology11110195

Keeler, B.L., Polasky, S., Brauman, K.A., Johnson, K.A., Finlay, J.C., O'Neill, A., Kovacs, K. & Dalzell, B. (2012). Linking water quality and well-being for improved assessment and valuation of ecosystem services. *PNAS, 109*(45), 18619–18624. https://doi.org/10.1073/pnas.1215991109

Klijn, F., Asselman, N. & Wagenaar, D. (2018). Room for Rivers: Risk Reduction by Enhancing the Flood Conveyance Capacity of The Netherlands' Large Rivers. *Geosciences*, 8(6), Article 224. https://doi.org/10.3390/geosciences8060224

Klijn, F., de Bruin, D., de Hoog, M.C., Jansen, S. & Sijmons, D.F. (2013) Design quality of room-for-the-river measures in the Netherlands: role and assessment of the quality team (Q-team), *International Journal of River Basin Management*, 11:3, 287-299, DOI: 10.1080/15715124.2013.811418

Knoll, L.B., Sharma, S., Denfeld, B.A., Flaim, G., Frassl, M.A., Grossart, H.P. & Weyhenmeyer, G.A. (2019). Consequences of lake and river ice loss on cultural ecosystem services. *Limnology and Oceanography Letters,* 4(5), 119–131. https://doi.org/10.1002/lol2.10116

Koebel Jr., J.W. (1995). An historical perspective on the Kissimmee River Restoration Project. Restoration Ecology 3(3):149 – 159, https://doi.org/10.1111/j.1526-100X.1995.tb00167.x

Koebel Jr., J.W. & Bousquin, S.G. (2014a). The Kissimmee River Restoration Project and Evaluation Program, Florida, U.S.A. *Restoration Ecology*, 22(3), 345-352. https://doi.org/10.1111/rec.12063

Koebel Jr., J.W. & Bousquin, S.G. (eds.) (2014b). The Kissimmee River Restoration Project: Ecological Monitoring and Assessment (SFWMD Technical Publication). *South Florida Water Management District*. https://apps.sfwmd.gov/sfwmd/SFER/2016_sfer_final/v1/chapters/v1_ch9.pdf.

Koh, Y.K., Zhang, Q. & Lee, S. (2022). Nature-based solutions in urban water management: Bishan-Ang Mo Kio Park in Singapore. *Water,* 14(10), 1610. https://doi.org/10.3390/w14101610

Kranney, D. (2019). Magpie geese return with help from ethical AI and Indigenous knowledge, CSIRO News, 22 November 2019. Commonwealth Scientific and Industrial Research Organisation, Black Mountain, ACT. Retrieved from https://www.csiro.au/en/news/All/Articles/2019/November/magpie-geese-return-ethical-ai-indigenous-knowledge.

Kumar, S., Sharma, L.K. & Fennessy, M.S. (2025). Global teal carbon: Stocks, sequestration, and its potential role in climate change mitigation. *Science of The Total Environment*, 995. https://doi.org/10.1016/j.scitotenv.2025.180128.

Lal, R. (2013). Soil carbon management and climate change, *Carbon Management*, 4(4), 439-462. https://doi.org/10.4155/cmt.13.31.

Lamers, L.P.M., Vile, M.A., Grootjans, A.P., Acreman, M.C., van Diggelen, R., Evans, M.G., Richardson, C.J., Rochefort, L., Kooijman, A.M., Roelofs, J.G.M. & Smolders, A.J.P. (2014). Ecological restoration of rich fens in Europe and North America: From trial and error to an evidence-based approach. *Biological Reviews*, 90(1), 182–203. https://doi.org/10.1111/brv.12102.

Le Maitre, D.C., Forsyth, G.G., Dzikiti, S. & Gush, M.B. (2016). Estimates of the impacts of invasive alien plants on water flows in South Africa. *Water SA*, 42(4), 659–672. https://doi.org/10.4314/wsa.v42i4.17

Lee, C.-K., Mjelde, J.W., Kim, T.-K., Lee, B.-K. & Choi, Y.-S. (2016). Revealed preference and effectiveness of public investment for ecological restoration: Use of the travel cost method to assess the Cheonggyecheon restoration project. *Sustainability, 8*(4), 353. https://doi.org/10.3390/su8040353

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

Leisher, C., Tiemann, J.S. & Chang, H. (2022). Socioeconomic and recreational impacts of dam removal on the Penobscot River, Maine, USA. *Journal of Environmental Management,* 308, 114541. https://doi.org/10.1016/j.jenvman.2022.114541

Li, T., Canadell, J.G., Yang, X.-Q., Zhai, P., Chao, Q., Lu, Y., Huang, D., Sun, W. & Qin, Z. (2022). Methane emissions from wetlands in China and their climate feedbacks in the 21st century. *Environmental Science & Technology*, 56(17), 12024–12035. https://doi.org/10.1021/acs.est.2c01575.

Liao, Q., Boucher, R., Wu, C., Noor, S., Liu, L., Rock, M., Flanner, M. & Holloway, L. (2020) Project: Hydrological Impact of Beaver Habitat Restoration in the Milwaukee River Watershed MMSD Contract P-2890 [Technical Report].

Liu, H., Wrage-Mönnig, N. & Lennartz, B. (2020a). Rewetting strategies to reduce nitrous oxide emissions from European peatlands. *Communications Earth & Environment*, 1, 17. https://doi.org/10.1038/s43247-020-00017-2.

Liu, W., Wei, X., Fan, H., Guo, X., Liu, Y., Zhang, M. & Li, Q. (2020b). Trade-offs between forest productivity and water yield in the upper Yangtze River basin. *Journal of Hydrology,* 590, 125473. https://doi.org/10.1016/j.jhydrol.2020.125473

Lloyd, L. & Finlayson, C. M. (2020). *Restoration of the Winton Wetlands: A community-driven conservation initiative*. Winton Wetlands Committee of Management. Retrieved from https://wintonwetlands.org.au/restoration

Logar, I., Brouwer, R. & Maurer, M. (2019). Assessing the benefits of river restoration: A valuation of ecosystem services in Switzerland. *Journal of Environmental Management,* 232, 1055–1065. https://doi.org/10.1016/j.jenvman.2018.11.014

Loth, P. (Ed.). (2004). The Return of the Water: Restoring the Waza-Logone Floodplain in Cameroon. IUCN, Wetlands and Water Resources Programme, Gland, Switzerland and Cambridge, UK. 156 pp. Retrieved from https://portals.iucn.org/library/node/8382.

Lynch, A.J., Cooke, S.J., Arthington, A.H., Baigun, C., Bossenbroek, L., Dickens, C., Harrison, I., Kimirei, I., Langhans, S.D., Murchie, K.J., Olden, J.D., Ormerod, S.J., Owuor, M., Raghavan, R., Samways, M.J., Schinegger, R., Sharma, S., Tachamo-Shah, R. D., Tickner, D., … Jähnig, S.C. (2023a). People need freshwater biodiversity. *WIREs Water* 10(3), e1633. https://doi.org/10.1002/wat2.1633

Lynch, A.J., Murchie, K.J. & Cooke, S.J. (2023b). Nine reasons why we humans need freshwater biodiversity. World Wide Fund for Nature (WWF). Global Water Forum. Retrieved from https://www.globalwaterforum.org/2023/05/22/people-need-freshwater-biodiversity-nine-reasons-freshwater-biodiversity-is-important-for-humans/

Lynch, A.J., Cooke, S.J., Deines, A.M., Bower, S.D., Bunnell, D.B., Cowx, I.G., Nguyen, V.M., Nohner, J. K., … Beard, T.D. Jr. (2016). The social, economic, and environmental importance of inland fish and fisheries. *Environmental Reviews, 24*(2), 115-121. https://doi.org/10.1139/er-2015-0064

Lynch, A.J., Elliott, V., Phang, S.C., Claussen, J.E., Harrison, I., Murchie, K.J., Steel, E.A. & Stokes, G.L. 2020. Inland fish and fisheries integral to achieving the Sustainable Development Goals. *Nature Sustainability,* 3, 579–587. https://doi.org/10.1038/s41893-020-0517-6

Lynch, A. J., Hyman, A. A., Cooke, S. J., Capon, S. J., Franklin, P. A., Jähnig, S. C., McCartney, M., Hòa, N. P., Owuor, M. A., Pittock, J., Samways, M. J., Silva, L. G. M., Steel, E. A. & Tickner, D. (2024). Future-proofing the emergency recovery plan for freshwater biodiversity. *Environmental Reviews*, 32(3), 350–365. https://doi.org/10.1139/er-2022-0116

Ma, S., Creed, I.F. & Badiou, P. (2024). New perspectives on temperate inland wetlands as natural climate solutions under different CO2-equivalent metrics. *npj Climate and Atmospheric Science*, 7, 222. https://doi.org/10.1038/s41612-024-00778-z.

Macdonald, A. & Robertson, H. (2017). Arawai Kākāriki Wetland Restoration Programme, Science Outputs 2007–2016. Department of Conservation, Wellington. https://www.wetlandtrust.org.nz/wp-content/uploads/2018/10/arawai-kakariki-bibliography-science-outputs.pdf.

MACH (Management of Aquatic Ecosystems through Community Husbandry) (2003). MACH Project. A Government of Bangladesh Project supported by USAID. Brochure. Retrieved from http://nishorgo.org/wp-content/uploads/2017/04/5-2-3-MACH-Brochure.pdf.

Maine Department of Marine Resources (2025). Historical Maine Alewife Landings (updated Feb 14, 2025). *State data table*. Retrieved from https://www.maine.gov/dmr/sites/maine.gov.dmr/files/inline-files/alewife.table__0.pdf,

Mansourian, S., Doncheva, N., Valchev, K. & Vallauri, D. (2019). Lessons learnt from 20 years of floodplain forest restoration: the Lower Danube Landscape. WWF Field Series. Paris: WWF France. Retrieved from https://wwfeu.awsassets.panda.org/downloads/lessons_learnt_from_20years_of_floodplain_forest_restoration_the_lower_danube_landscap.pdf

Marais, C. & Wannenburgh, A.M. (2008). Restoration of water resources (natural capital) through the clearing of invasive alien plants from riparian areas in South Africa — Costs and water benefits. *South African Journal of Botany,* 74(3), 526–537. https://doi.org/10.1016/j.sajb.2008.01.175

Mazzola, V., Perks, M.P., Smith, J., Yeluripati, J. & Xenakis, G. (2020). Seasonal patterns of greenhouse gas emissions from a forest-to-bog restored site in northern Scotland: Influence of microtopography and vegetation on carbon dioxide and methane dynamics. *European Journal of Soil Science*, 72, 1332–1353, https://doi.org/10.1111/ejss.13050.

McCrackin, M.L., Jones, H.P., Jones, P.C. & Moreno-Mateos, D. (2017). Recovery of lakes and coastal marine ecosystems from eutrophication: A global meta-analysis. *Limnology and Oceanography*, 62(2), 507–518. https://doi.org/10.1002/lno.10441

McIntyre, P.B., Reidy, C.A. & Revenga, C. (2016). Linking freshwater fishery management to global food security and biodiversity conservation. *PNAS*, 113(45). https://doi.org/10.1073/pnas.1521540113.

McMaster, D., Adams, V., Setterfield, S., McIntyre, D. & Douglas, M. (2014). Para grass management and costing trial within Kakadu National Park. In *Proceedings of the 19th Australasian Weeds Conference*, pp. 129–133. Tasmanian Weed Society. Retrieved from https://caws.org.nz/old-site/awc/2014/awc201411291.pdf.

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*, 201623(7). https://doi.org/10.1111/gcb.13580.

Meaza, H. Abera, W. & Nyssen, J. (2022) Impacts of catchment restoration on water availability and drought resilience in Ethiopia: A meta-analysis. *Land Degradation and Development*, 33(4), 547-564. https://doi.org/10.1002/ldr.4125

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Island Press. Retrieved from https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Mitsch, W.J. & Gosselink, J.G. (2015). *Wetlands*, 5th ed. Hoboken, NJ: John Wiley & Sons, Inc.

Mitsch, W.J., Bernal, B., Nahlik, A.M., Mander, Ü., Zhang, L., Anderson, C.J., Jørgensen, S.E. & Brix, H. (2013). Wetlands, carbon, and climate change. *Landscape Ecology*, 28(4), 583–597. https://doi.org/10.1007/s10980-012-9758-8.

Mohammed, E.Y., Haque, A.B.M.M. & Nahiduzzaman, M. (2025). Impact evaluation of hilsa fishery restoration in Bangladesh: money well spent? *Frontiers in Marine Science*, 11, 1437783. https://doi.org/10.3389/fmars.2024.1437783.

Moomaw, W.R., Chmura, G.L., Davies, G.T., Finlayson, C.M., Middleton, B.A., Natali, S.M., Perry, J.E., Roulet, N. & Sutton-Grier, A.E. (2018). Wetlands in a changing climate: Science, policy and management. *Wetlands*, 38(2), 183–205. https://doi.org/10.1007/s13157-018-1023-8.

Moreno-Mateos, D., Power, M.E., Comín, F.A. & Yockteng, R. (2012). Structural and functional loss in restored wetland ecosystems. *PLoS Biology*, 10(1), e1001247. https://doi.org/10.1371/journal.pbio.1001247

Morrison, E.H.J. (2013). Ecological restoration of papyrus wetlands at Lake Naivasha, Kenya: social and ecological considerations. Doctoral dissertation, Department of Geography, University of Leicester, Leicester, UK. Retrieved from https://figshare.le.ac.uk/articles/thesis/Ecological_restoration_of_papyrus_wetlands_at_Lake_Naivasha_Kenya_social_and_ecological_considerations/10147049?file=18286820.

Morrison, E.H.J., Upton, C., Odhiambo-K'oyooh, K. & Harper, D. M. (2012). Managing the natural capital of papyrus within riparian zones of Lake Victoria, Kenya. *Hydrobiologia*, 692, 5–17. https://doi.org/10.1007/s10750-011-0839-5.

Morrison, E.H.J., Upton, C., Pacini, N., Odhiambo-K'oyooh, K. & Harper, D.M. (2013). Biomass briquettes: a novel incentive for managing papyrus wetlands sustainably? *Wetlands Ecology and Management*, 21, 381–392. https://doi.org/10.1007/s11273-013-9310-x

Mrozińska, N., Glińska-Lewczuk, K., Burandt, P., Kobus, S., Gotkiewicz, W., Szymańska, M., Bąkowska, M. & Obolewski, K. (2018). Water quality as an indicator of stream restoration effects—A case study of the Kwacza River restoration project. *Water*, 10(9), Article 1249. https://doi.org/10.3390/w10091249

Mu, X., Wang, Q., Shi, X., Liu, S., Wang, L. & Song, Y. (2022). Optimal spatial patterns for balancing multiple ecosystem services in the Lower Liao River basin, China. *Journal of Environmental Management,* 318, 115560. https://doi.org/10.1016/j.jenvman.2022.115560

Multidisciplinary Expert Panel. (2023). *Information note on applying "nature's contributions to people"* [Note by the Multidisciplinary Expert Panel]. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://files.ipbes.net/ipbes-web-prod-public-files/inline-files/ipbes_mep_note%20on%20NCP%20by%20MEP.pdf

Murray–Darling Basin Authority (MDBA). (2024). Hattah Lakes – Monitoring reports. Murray–Darling Basin Authority, Canberra. https://www.mdba.gov.au/publications-and-data/publications/hattah-lakes-monitoring-reports.

National Academies of Sciences, Engineering, and Medicine. (2020). *Review of the New York City Watershed Protection Program*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25851

National Research Council. (1992). *Restoration of aquatic ecosystems: Science, technology, and public policy*. Washington, DC: National Academy Press.

Nguyen, V.K., Vo, O.V. & Huynh, D.N. (2015). Comparing the costs and benefits of floating rice-based and intensive rice-based farming systems in the Mekong Delta. *Asian Journal of Agriculture and Rural Development*, 5(9), 202–217. Retrieved from https://archive.aessweb.com/index.php/5005/article/view/1402.

Nilsson, C., Riis, T., Sarneel, J. M. & Svavarsdóttir, K. (2018). Ecological restoration as a means of managing inland flood hazards. *BioScience*, 68(2), 89–99. https://doi.org/10.1093/biosci/bix148

NOAA Fisheries. (2024). *Dam removals on the Elwha River.* NOAA Fisheries, West Coast Region. Retrieved from https://www.fisheries.noaa.gov/west-coast/science-data/dam-removals-elwha-river

Noe, G.B. & Hupp, C.R. (2009). Retention of riverine sediment and nutrient loads by Coastal Plain floodplains. *Ecosystems*, 12(5), 728–746. https://doi.org/10.1007/s10021-009-9253-5

Ogston, L., Gidora, S., Foy, M. & Rosenau, M. (2014). Watershed-scale effectiveness of floodplain habitat restoration for juvenile coho salmon in the Chilliwack River, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences,* 72(4), 479–490. https://doi.org/10.1139/cjfas-2014-0189

Olander, L.P., Johnston, R.J., Tallis, H., Kagan, J., Maguire, L.A., Polasky, S., Urban, D., Boyd, J., Wainger, L. & Palmer, M. (2018). Benefit-relevant indicators: Ecosystem services measures that link ecological and social outcomes. *Ecological Indicators,* 85, 1262–1272. https://doi.org/10.1016/j.ecolind.2017.12.001

Opperman, J.J., Luster, R., McKenney, B.A., Roberts, M. & Meadows, A.W. (2010). Ecologically Functional Floodplains: Connectivity, Flow Regime, and Scale. *Journal of the American Water Resources Association*, 46(2), 211–226. https://doi.org/10.1111/j.1752-1688.2010.00426.x.

Our World in Data. (2024). Global damage costs from natural disasters, FLOOD, 1980 – 2024. Sourced from EM-DAT, Centre for Research on the Epidemiology of Disasters, (CRED), Institute of Health & Society (IRSS), Université catholique de Louvain, Brussels. Retrieved from https://ourworldindata.org/grapher/damage-costs-from-natural-disasters?country=~Flood

Palmer, M.A., Menninger, H.L. & Bernhardt, E. (2010). River restoration, habitat heterogeneity and biodiversity: A failure of theory or practice? *Freshwater Biology*, 55(suppl. 1), 205–222. https://doi.org/10.1111/j.1365-2427.2009.02372.x

Peacock, R., Bently, M., Rees, P. & Blignaut, J.N. (2023). The benefits of ecological restoration exceed its cost in South Africa: An evidence-based approach. *Ecosystem Services,* 61, 101528. https://doi.org/10.1016/j.ecoser.2023.101528

Pedersen, M.L., Andersen, J.M., Nielsen, K. & Linnemann, M. (2007). Restoration of Skjern River and its valley: Project description and general ecological changes in the project area. *Ecological Engineering*, 30(2), 131–144. https://doi.org/10.1016/j.ecoleng.2006.06.009

Pegram, G. C., Li, Y. Y., Le Quesne, T., Speed, R., Li, J. & Shen, F. (2013). *River basin planning: principles, procedures and approaches for strategic basin planning*. Manila, Philippines: Asian Development Bank.

Pendea, I.F., Kanavillil, N., Kurissery, S. & Chmura, G.L. (2023). Carbon Stocks and Recent Rates of Carbon Sequestration in Nutrient-Rich Freshwater Wetlands From Lake Simcoe Watershed (Southern Canada). *Journal of Geophysical Research: Biogeosciences*, 128(10). https://doi.org/10.1029/2023JG007561.

Perkins, D.M., Hull, T., Bubb, N., Cunningham, A., Glackin, R., Glen, T., Smith, S. & Davies, B. (2021). Putting the "beaver" back in Beverley Brook: Rapid shifts in community composition following the restoration of a degraded urban river. *Water,* 13(24), 3530. https://doi.org/10.3390/w13243530

Petersen, T.A., Brum, S.M., Rossoni, F., Silveira, G.F.V. & Castello, L. (2016). Recovery of *Arapaima* sp. populations by community-based management in floodplains of the Purus River, Amazon. *Journal of Fish Biology*, 89(1), 241–248. https://doi.org/10.1111/jfb.12968.

Petsch, D.K., de Mello Cionek, V., Thomaz, S.M. & Lacerda Santos, N.C. (2023). Ecosystem services provided by river-floodplain ecosystems. *Hydrobiologia*, 849, 2337–2354. https://doi.org/10.1007/s10750-022-04916-7

Pfeifer-Meister, L., Gayton, L.G., Roy, B.A., Johnson, B.R. & Bridgham, S.D. (2018). Greenhouse gas emissions limited by low nitrogen and carbon availability in natural, restored, and agricultural Oregon seasonal wetlands. *PeerJ*, 6, e5465. https://doi.org/10.7717/peerj.5465.

Phala, C., Sarin, T., Suvedi, M. & Ghimire, R. (2019). Assessment of community fish refuge management practice in the Siem Reap Province of Cambodia. *Environments*, 6(1), 1. https://doi.org/10.3390/environments6010001.

Pijlman, J., Geurts, J., Vroom, R., Bestman, M., Fritz, C. & van Eekeren, N. (2019). The effects of harvest date and frequency on the yield, nutritional value and mineral content of the paludiculture crop cattail (*Typha latifolia L*.) in the first year after planting. *Mires and Peat*, 25, 04. https://doi.org/10.19189/MaP.2017.OMB.325,

Pingram, M.A., Collier, K.J., Williams, A.K., David, J. Garrett-Walker, B.O., Górski, K., Özkundakci, D. & Ryan, E.F. (2021). Surviving invasion: regaining native fish resilience following fish invasions in a modified floodplain landscape. *Water Resources Research*, **57**(9), e2020WR029513. https://doi.org/10.1029/2020WR029513.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. & Stromberg, J.C. (1997). The natural flow regime. *BioScience*, 47(11), 769–784. https://doi.org/10.2307/1313099.

Ponting, J., Kelly, T.J., Verhoef, A. & Watts, M.J. (2021). The impact of increased flooding occurrence on the mobility of potentially toxic elements in floodplain soil – A review. *Science of The Total Environment,* 777, 146114. https://doi.org/10.1016/j.scitotenv.2021.146114

Postel, S. (2005). *Liquid Assets: The Critical Need to Safeguard Freshwater Ecosystems*. Worldwatch Paper 170, Mastny, L. (Ed.), Washington, DC: Worldwatch Institute, July.

Public Utilities Board (PUB), Singapore. (2018). *ABC Waters Design Guidelines: Active, Beautiful, Clean Waters Programme*, 4th ed. PUB, Government of Singapore. Retrieved from https://www.pub.gov.sg/Documents/ABC_Waters_Design_Guidelines.pdf

Puttock, A., Graham, H. A., Carless, D. & Brazier, R. E. (2018). Sediment and nutrient storage in a beaver engineered wetland. *Earth Surface Processes and Landforms*, 43(11), 2358–2370. https://doi.org/10.1002/esp.4398

Puttock, A., Graham, H. A., Ashe, J., Luscombe, D. J. & Brazier, R. E. (2021). Beaver dams attenuate flow: A multi-site study. *Hydrological Processes*, 35(2), e14017. https://doi.org/10.1002/hyp.14017

Ramsar Convention on Wetlands (2018). *Global Wetland Outlook: State of the World's Wetlands and their Services to People*. Gland, Switzerland: Ramsar Convention Secretariat. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3261606.

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T.J., Kidd, K.A., MacCormack, T.J., Olden, J.D., Ormerod, S.J., Smol, J.P., Taylor, W.W., Tockner, K., Vermaire, J.C., Dudgeon, D. & Cooke, S.J. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, 94(3), 849–873. https://doi.org/10.1111/brv.12480.

Renou-Wilson, F., Wilson, D., Rigney, M., Byrne, K. A., Farrell, C.A. & Müller, C. (2019). Rewetting degraded peatlands for climate and biodiversity benefits: Results from the Irish LIFE project. *Mires and Peat*, 24, 1–21. https://doi.org/10.19189/MaP.2018.OMB.368

Rey Benayas, J.M., Newton, A.C., Díaz, A. & Bullock, J.M. (2009). Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. *Science*, 325(5944), 1121–1124. https://doi.org/10.1126/science.1172460

Richardson, C.J. & Hussain, N.A. (2006). Restoring the Garden of Eden: An ecological assessment of the marshes of Iraq. *BioScience*, 56(6), 477–489. https://doi.org/10.1641/0006-3568(2006)56[477:RTGOEA]2.0.CO;2.

Richardson, C.J., Flanagan, N.E. & Ho, M.C. (2023). The effects of hydrologic restoration on carbon budgets and GHG fluxes in southeastern US coastal shrub bogs. *Ecological Engineering*, 194, 107011. https://doi.org/10.1016/j.ecoleng.2023.107011.

Ringler, C., Agbonlahor, M., Barron, J., Baye, K., Meenakshi, J.V., Mekonnen, D.K. & Uhlenbrook, S. (2022). The role of water in transforming food systems. *Global Food Security*, 33, 100639. https://doi.org/10.1016/j.gfs.2022.100639.

Rodrigues, J.M G. (2015) Cultural services in aquatic ecosystems. In I. D. Zalewski (Ed.), *Ecosystem services and river basin ecohydrology* (pp. 25–36). Springer. https://doi.org/10.1007/978-94-017-9846-4_3

Rubin, S.P., Miller, I.M., Foley, M.M., Berry, H.D., Duda, J.J., Hudson, B., Elder, N.E., Beirne, M.M., Warrick, J.A., McHenry, M.L., Stevens, A.W., Eidam, E.F., Ogston, A.S., Gelfenbaum, G.R. & Pedersen, R. (2017). Increased sediment load during a large-scale dam removal changes nearshore subtidal communities. *PLOS ONE,* 12(12), e0187742. https://doi.org/10.1371/journal.pone.0187742

Russi, D., ten Brink, P., Farmer, A., Baďura, T., Coates, D., Förster, J., Kumar, R. & Davidson, N. (2013). *The Economics of Ecosystems and Biodiversity for Water and Wetlands*. London & Brussels: Institute for European Environmental Policy (IEEP); Gland: Ramsar Secretariat.

Sapir, G., Angert, A., Rosenberg, Y.O. & Golan, R. (2025). Long-term effects of drainage and rewetting on the degradation and preservation of peat organic matter in warm climate. *EGUsphere*. https://doi.org/10.5194/egusphere-2025-2763.

Sayer, C.A., Fernando, E., Jimenez, R.R., Macfarlane, N.B.W., Rapacciuolo, G., Böhm, M., Brooks, T. M., Contreras-MacBeath, T., Cox, N. A., Harrison, I., Hoffmann, M., Jenkins, R., Smith, K.G., Vié, J.-C., Abbott, J.C., Allen, D.J., Allen, G.R., Barrios, V., Boudot, J.-P. … Darwall, W.R.T. 2025. One-quarter of freshwater fauna threatened with extinction. *Nature*, 638, 138–145. https://doi.org/10.1038/s41586-024-08375-z

Schaller, C., Hofer, B. and Klemm, O. (2022). Greenhouse gas exchange of a NW German peatland, 18 years after rewetting. *Journal of Geophysical Research: Biogeosciences*, 127, e2020JG005960. https://doi.org/10.1029/2020JG005960.

Scholte, P., Kari, S., Moritz, M. & Prins, H. (2006). Pastoralist responses to floodplain rehabilitation in North Cameroon. *Human Ecology*, 34(1), 27–51. https://doi.org/10.1007/s10745-005-9001-1.

Schuster, L., Taillardat, P., Macreadie, P.I. & Malerba, M.E. (2024). Freshwater wetland restoration and conservation are long-term natural climate solutions. *Science of the Total Environment*, 922, 171218. https://doi.org/10.1016/j.scitotenv.2024.171218

Schwerk, A., Carvalho, L., Spears, B., Williamson, J., Pott, L., Kajner, P., Okruszko, T., Ádám, S., Baattrup-Pedersen, A., Balogh, P., Bañares, I., Barbosa, H., Beranen, L.L., Boets, P., Cardoso, S., Colls, M., Duarte, G., Ecke, F., Ecker, T. … Birk, S. (2025). Manuscript and policy briefing evaluating success of large landscape-scale restoration. EU H2020 research and innovation project MERLIN Deliverable D1.6. 135 pp. https://project-merlin.eu/outcomes/deliverables.html

Serra-Llobet, A., Thorne, J.H., Kondolf, G.M., Woo, I. & Mouillon, M. (2022). Restoring rivers and floodplains for habitat and flood risk reduction: Experiences in multi-benefit floodplain restoration from Germany and California. *Frontiers in Environmental Science,* 10, 778568. https://doi.org/10.3389/fenvs.2022.778568

Silva, M.R.O., Castello, L., Freitas, C.T., Campos-Silva, J.V., Peres, C.A. & Novo, E.M.L.M. (2025). Comanagement and reconciling of ecological and economic benefits in an Amazonian freshwater fishery. *Conservation Biology*, 39(3), e70035. https://doi.org/10.1111/cobi.70035

South Australian Environment Protection Authority (EPA). (2008). Water quality in the Myponga Reservoir Catchment: 1999–2007. Adelaide: Government of South Australia.

South Florida Water Management District (n.d.). Kissimmee River Restoration Phase I Environmental Recovery is Under Way. South Florida Water Management District, West Palm Beach, FL. https://www.sfwmd.gov/sites/default/files/documents/bts_krr_phase_1.pdf

Speed, R., Li, Y., Tickner, D., Huang, H., Naiman, R. J., Cao, J., Lei, G., Yu, L., Sayers, P., Zhao, Z. & Wei, Y. (2016a). A framework for strategic river restoration in China. *Water International,* 41(7), 998–1015. https://doi.org/10.1080/02508060.2016.1247311

Speed, R., Li, Y., Tickner, D., Huang, H., Naiman, R., Cao, J., Lei, G., Yu, L., Sayers, P., Zhao, Z. & Wei, Y. (2016b). *River restoration: A strategic approach to planning and management*. UNESCO Publishing.

Spencer, J., Preston, D., Humphries, J., Cain, V., Ocock, J., Shrubb, J. & Southwell, M. 2023. Waterbird breeding in the Gwydir Wetlands, 2022-23. A report to the Commonwealth Environmental Water Office, Canberra. Retrieved from https://www.dcceew.gov.au/sites/default/files/documents/gwydir-appendix-h-waterbird-breeding-2022-23.pdf.

Spencer, L.J. & Bousquin, S.G. 2014. Interim Responses of Floodplain Wetland Vegetation to Phase I of the Kissimmee River Restoration Project: Comparisons of Vegetation Maps from Five Periods in the River's History. *Restoration Ecology*, 22(3), 397-408. https://doi.org/10.1111/rec.12074

Steel, E.A., Obiang Ndong, G., Adelola, T., Aggestam, F., Akwany, L., Bezerra, M., Casallas Ramirez, S., Colvin, C., Crane, S., Feist, B.E., Finegold, Y., Friedman, K., Fox, J., Garcia, N., Hagger, V., Irvine, K., Lucas, B., Nel, J., Nyolei, D., Pokhrel, P.R. … Vollmer, D. 2025. *Enabling consistent reporting and monitoring for freshwater (inland waters) restoration under Target 2 of the Kunming-Montreal Global Biodiversity Framework*. Rome, FAO. https://doi.org/10.4060/cd5046en

Sterner, R.W., Keeler, B., Polasky, S., Poudel, R., Rhude, K. & Rogers, M. (2020). Ecosystem services of Earth's largest freshwater lakes. *Ecosystem Services,* 41, 101046. https://doi.org/10.1016/j.ecoser.2019.101046

Strack, M. & Zuback, Y.C.A. (2013). Annual carbon balance of a peatland 10 yr following restoration. *Biogeosciences,* 10 (5), 2885–2896. https://doi.org/10.5194/bg-10-2885-2013.

Strayer, D.L. & Dudgeon, D. (2010). Freshwater biodiversity conservation: Recent progress and future challenges. *Journal of the North American Benthological Society*, 29(1), 344–358. https://doi.org/10.1899/08-171.1

Taillardat, P., Thompson, B.S., Garneau, M., Trottier, K. & Friess, D.A. (2020). Climate change mitigation potential of wetlands and the cost-effectiveness of their restoration. *Interface Focus*, 10(5), 1020190129. http://doi.org/10.1098/rsfs.2019.0129.

Tan, L.C. & Loke, L. (2012). Bishan-Ang Mo Kio Park and the Kallang River restoration project, Singapore: A case study of interdisciplinary design. *International Federation of Landscape Architects (IFLA) World Congress Proceedings,* 1–12.

Tangen, B. & Bansal, S. (2020). Soil organic carbon stocks and sequestration rates of inland, freshwater wetlands: Sources of variability and uncertainty. *Science of the Total Environment*, 749, 141444. https://doi.org/10.1016/j.scitotenv.2020.141444.

Temmink, R.J.M., Joosten, H. & van der Wal, R. (2023). Peatland rewetting and paludiculture: Challenges and opportunities in Europe. *Ambio,* 52(1), 29–42. https://doi.org/10.1007/s13280-022-01759-9

Temmink, R. J. M., Vroom, R. J. E., van Dijk, G., Käärmelahti, S. A., Koks, A. H. W., Joosten, H., Krebs, M., Gaudig, G., Brust, K., Lamers, L. P. M., Smolders, A. J. P. & Fritz, C. (2024). Restoring organic matter, carbon and nutrient accumulation in degraded peatlands: 10 years Sphagnum paludiculture. *Biogeochemistry,* 167(4), 347–361. https://doi.org/10.1007/s10533-023-01065-4

The Nature Conservancy. (2015). *Upper Tana-Nairobi Water Fund: A business case* (Version 2). Nairobi, Kenya. Retrieved from https://www.nature.org/content/dam/tnc/nature/en/documents/Nairobi-Water-Fund-Business-Case_FINAL.pdf

Thompson, J.B., Zurita-Arthos, L., Müller, F., Chimbolema, S. & Suárez, E. (2021). Land use change in the Ecuadorian páramo: The impact of expanding agriculture on soil carbon storage. *Arctic, Antarctic, and Alpine Research*, 53(1), 48–59. https://doi.org/10.1080/15230430.2021.1873055.

Thompson, P.M. (2008). Conserving and restoring the benefits from Bangladesh wetlands. Paper presented at the *12th International Association for the Study of Commons* conference, University of

Gloucestershire 14-18 July 2008. Retrieved from https://www.cbd.int/financial/values/bangladesh-hailhaorwetlands.pdf,

Tickner, D., Opperman, J. J., Abell, R., Acreman, M., Arthington, A. H., Bunn, S. E., Cooke, S. J., Dalton, J., Darwall, W., Edwards, G., Harrison, I., Hughes, K., Jones, T., Leclère, D., Lynch, A. J., Leonard, P., McClain, M. E., Muruven, D., Olden, J. D….Young, L. (2020). Bending the curve of global freshwater biodiversity loss: An emergency recovery plan. *BioScience,* 70(4), 330–342. https://doi.org/10.1093/biosci/biaa002

Tölgyesi, C., Csikós, N., Temperton, V.M., Buisson, E., Silveira, F.A.O., Lehmann, C.E.R., Török, P., Bátori, Z. & Bede-Fazekas, Á. (2025). Limited carbon sequestration potential from global ecosystem restoration. *Nature Geoscience*, 18(8), 761-768. https://doi.org/10.1038/s41561-025-01742-z.

Toth, L.A. (2002). Kissimmee River restoration: A case study. *Water Science and Technology*, 45(11), 55–62. https://doi.org/10.2166/wst.2002.0379.

UK Department for Environment, Food & Rural Affairs (DEFRA). (2021). The state of the water environment in England, 2021 Report. London, UK: DEFRA. Retrieved from https://www.gov.uk/government/publications/state-of-the-water-environment-in-england-2021

UN-Water (2018). Valuing rivers: how the diverse benefits of rivers underpin economies. UN-Water (web feature). Geneva, Switzerland, 25 October. Retrieved from https://www.unwater.org/news/valuing-rivers-how-diverse-benefits-rivers-underpin-economies.

UNESCO World Heritage Centre. (2010). State of Conservation (SOC) report: Ichkeul National Park (N 8), Tunisia. UNESCO World Heritage Centre, Paris. Retrieved from https://whc.unesco.org/en/soc/482.

UNESCO. (2021). *UN World Water Development Report 2021: Valuing water*. United Nations Educational, Scientific and Cultural Organization, Paris. Retrieved from https://www.unesco.org/reports/wwdr/2021/en

UNESCO. (2023). *UN World Water Development Report 2023. Partnerships and Cooperation for Water*. United Nations Educational, Scientific and Cultural Organization, Paris. Retrieved from https://www.unesco.org/reports/wwdr/2023/en

UNESCO. (2024). *UN World Water Development Report 2024: Water for Prosperity and Peace – Key Statistics*. United Nations Educational, Scientific and Cultural Organization, Paris. Retrieved from https://www.unesco.org/en/articles/united-nations-world-water-development-report-2024-water-prosperity-and-peace

United Nations Environment Programme & United Nations Water (UNEP & UNW). (2024). *Progress on Water-related Ecosystems: Mid-term Status of SDG Indicator 6.6.1 and Acceleration Needs with a Special Focus on Biodiversity*. Retrieved from https://wedocs.unep.org/20.500.11822/46107

United Nations Environment Programme (UNEP). (2021). *Progress on freshwater ecosystems: Tracking SDG 6 series – Global indicator 6.6.1 updates and acceleration needs*. UNEP. Retrieved from https://wedocs.unep.org/handle/20.500.11822/36691

United Nations Environment Programme (UNEP). (n.d.). *Goal 6: Clean water and sanitation*. Retrieved from https://www.unep.org/topics/sustainable-development-goals/why-do-sustainable-development-goals-matter/goal-6

United Nations Office for Disaster Risk Reduction (UNDRR). (2015). *Sendai Framework for Disaster Risk Reduction 2015–2030*. Retrieved from https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

United Nations Office for Disaster Risk Reduction (UNDRR). (2022). *Global assessment report on disaster risk reduction 2022*. UNDRR. Retrieved from https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2022

United Nations, Department of Economic and Social Affairs. (n.d.). *Better data for water-related disasters* [Partnership Platform profile]. Retrieved from https://sdgs.un.org/partnerships/better-data-water-related-disasters

United Nations. (1992). *United Nations Framework Convention on Climate Change*. Retrieved from https://unfccc.int/resource/docs/convkp/conveng.pdf

United Nations. (1994). *United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa.* Retrieved from https://www.unccd.int/resource/convention-text

United Nations. (2015). *Paris Agreement*. Retrieved from https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf

US Army Corps of Engineers (n.d.). Kissimmee River Restoration Project. Facts & Information. Retrieved from https://www.jkgeography.com/uploads/1/0/8/4/108433405/kissimmee_river_restoraton_project.pdf.

Van Alphen, S. (2019). Room for the River: Innovation, or Tradition? The Case of the Noordwaard. In *Adaptive Strategies for Water Heritage* (pp. 308–323). Springer. https://doi.org/10.1007/978-3-030-00268-8_16

van Dijk, A.I.J.M. & Keenan, R.J. (2007). Planted forests and water in perspective. *Forest Ecology and Management,* 251(1–2), 1–9. https://doi.org/10.1016/j.foreco.2007.06.010

Van Leeuwen, C., Temmink, R., Jin, H., Kahlert, Y., Robroek, B., Berg, M., Lamers, L., van den Akker, M., Posthoorn, R., Boosten, A., Olff, H. & Bakker, E. (2021). Enhancing ecological integrity while preserving ecosystem services: Constructing soft-sediment islands in a shallow lake. *Dryad*. https://doi.org/10.5061/dryad.2v6wwpznx

Vermaat, J.E., Wagtendonk, A.J., Brouwer, R., Sheremet, O., Ansink, J.H., Brockhoff, T., Plug, M., Hellsten, S., Aroviita, J., Tylec, L., Giełczewski, M., Kohut, L., Brabec, K., Haverkamp, J., Poppe, M., Böck, K., Coerssen, M., Segersten, J. & Hering, D. (2016). Assessing the societal benefits of river restoration using the ecosystem services approach. *Hydrobiologia*, 769(1), 121–135. https://doi.org/10.1007/s10750-015-2482-z

Vicarelli, M., Delacámara, G., Martínez-López, J., Broekx, S., Cortés, U., Giampietro, M. & Gómez, C. M. (2024). Global evidence of the effectiveness and cost-effectiveness of nature-based solutions for flood risk reduction: A systematic review. *Science of The Total Environment,* 921, 168156. https://doi.org/10.1016/j.scitotenv.2024.168156

Völker, S. & Kistemann, T. (2011). The impact of blue space on human health and well-being: Salutogenetic health effects of inland surface waters—A review. *International Journal of Hygiene and Environmental Health,* 214(6), 449–460. https://doi.org/10.1016/j.ijheh.2011.05.001

Walsh, C. J., Imberger, M. J., Burns, M. J., Bos, D. G. & Fletcher, T. D. (2022). Dispersed urban-stormwater control improved stream water quality in a catchment-scale experiment. *Water Resources Research*, 58(12), Article e2022WR032041. https://doi.org/10.1029/2022WR032041

Waltham, N. J., Burrows, D., Wegscheidl, C., Buelow, C., Ronan, M., Connolly, N., Groves, P., Marie-Audas, D., Creighton, C. & Sheaves, M. (2019). Lost floodplain wetland environments and efforts to restore connectivity, habitat, and water quality settings on the Great Barrier Reef. *Frontiers in Marine Science*, 6, 71. https://doi.org/10.3389/fmars.2019.00071

Watson, K. B., Ricketts, T. H., Galford, G. L., Polasky, S. & O'Niel-Dunne, J. (2016). Quantifying flood mitigation services: The economic value of Otter Creek wetlands and floodplains to Middlebury, VT. *Ecological Economics*, 130, 16–24. https://doi.org/10.1016/j.ecolecon.2016.05.015

Watts, R.J., Bond, N., Healy, S., Liu, X., McCasker, N., Michie, L., Siebers, A., Thiem, J. & Trethewie, J. (2022). Commonwealth Environmental Water Office Monitoring, Evaluation and Research Project: Edward/Kolety-Wakool Flow Selected Area *Technical Report 2021-22*. Commonwealth Environmental Water Office, Commonwealth of Australia. Retrieved from https://www.dcceew.gov.au/water/cewo/publications/cewo-mer-edward-kolety-wakool-selected-area-reports-2021-22.

Westbrook, C.J., Cooper, D.J. & Baker, B.W. (2006). Beaver dams and overbank floods influence groundwater–surface water interactions of a Rocky Mountain riparian area. *Water Resources Research,* 42(6), W06404. https://doi.org/10.1029/2005WR004560

Weyl, O.L.F., Barrow, S., Bellingan, T., Dalu, T., Ellender, B.R., Esler, K., Impson, D., Gouws, J., Jordaan, M., Villet, M., Wassermann, R.J., and Woodford, D.J. (2016). Monitoring of invertebrate and fish recovery following river rehabilitation by removal of alien fishes in the Rondegat River (Report No. K5/2261). Water Research Commission. Pretoria, South Africa. Retrieved from https://www.wrc.org.za/wp-content/uploads/mdocs/2261.pdf.

Weyl, O.L.F., Finlayson, B., Impson, N.D., Woodford, D.J. & Steinkjer, J. (2014). Threatened endemic fishes in South Africa's Cape Floristic Region: A new beginning for the Rondegat River. *Fisheries*, 39, 270–279. https://doi.org/10.1080/03632415.2014.914924

Whalen, P.J., Toth, L.A., Koebel Jr, J.W. & Trayer, P.K. 2002. Kissimmee River Restoration: a case study. *Water Science and Technology*, 45(11), 55-62. https://doi.org/10.2166/wst.2002.0379.

White, E., Baker, C. & Gee, E. (2022). Restoration of whitebait populations in the lower Waikato River - fish passage barrier remediation. Waikato River Authority, NIWA (National Institute of Water & Atmospheric Research Ltd), Hamilton, NZ, July. Retrieved from http://waikatoriver.org.nz/wp-content/uploads/2022/07/2022-NIWA-Hamilton-Streams-report.pdf.

White, H.L., Fellows, R., Woodford, L., Ormsby, M.J., van Biervliet, O., Law, A., Quilliam, R.S. & Willby, N.J. (2025). The impact of beaver dams on distribution of waterborne Escherichia coli and turbidity in an agricultural landscape. *Science of the Total Environment*, 968, 178871. https://doi.org/10.1016/j.scitotenv.2025.178871

Whittum, K.A., Zydlewski, J.D., Coghlan, S.M., Jr., Hayes, D.B., Watson, J. & Kiraly, I. (2023). Fish assemblages in the Penobscot River: A decade after dam removal. *Marine and Coastal Fisheries*, 15(1), e10227. https://doi.org/10.1002/mcf2.10227.

Wilcock, R.J., Monaghan, R.M., Quinn, J.M., Srinivasan, M.S., Houlbrooke, D.J., Duncan, M.J., Wright-Stow, A.E., & Scarsbrook, M.R. (2013). Trends in water quality of five dairy-farming streams in response to adoption of best practice and benefits of long-term monitoring at the catchment scale. *Marine and Freshwater Research*, 64(5), 401–412. https://doi.org/10.1071/MF12155

Williams, K. M., & Turner, A. M. (2015). Acid mine drainage and stream recovery: Effects of restoration on water quality, macroinvertebrates, and fish. *Knowledge and Management of Aquatic Ecosystems*, 416, 18. https://doi.org/10.1051/kmae/2015014

Wilson, D., Farrell, C., Fallon, D., Moser, G., Müller, C. & Renou-Wilson, F. (2016). Multi-year greenhouse gas balances at a rewetted temperate peatland. *Global Change Biology*, 22(12), 4080-4095. https://doi.org/10.1111/gcb.13325.

Wilson, D., Mackin, F., Tuovinen, J.-P., Moser, G., Farrell, C., & Renou-Wilson, F. (2022). Carbon and climate implications of rewetting a raised bog in Ireland. *Global Change Biology*, 28(21), 6349-6365. https://doi.org/10.1111/gcb.16359.

Winrock International (2007). MACH-II Completion Report Volume 1. (Management of Aquatic Ecosystems through Community Husbandry). Bangladesh Centre for Advanced Studies Center for Natural Resource Studies, CARITAS Bangladesh, June. Retrieved from https://nishorgo.org/wp-content/uploads/2017/04/2-1-1-Completion-Report-Vol-1.pdf,

Wohl, E., Lane, S. N. & Wilcox, A. C. (2015). The science and practice of river restoration. *Water Resources Research*, 51(8), 5974–5997. https://doi.org/10.1002/2014WR016874.

World Bank. (2009). Environmental and social impact assessment (Executive Summary): Río Bogotá Environmental Recuperation and Flood Control Project (Draft). Washington, DC: World Bank. Retrieved from https://documents1.worldbank.org/curated/en/980411468261323465/pdf/508800BR0P1114101Official0use0only1.pdf

World Bank. (2019a). Implementation status and results report: Río Bogotá Environmental Recuperation and Flood Control Project (P111479), sequence no. 17. Washington, DC: World Bank. Retrieved from https://documents1.worldbank.org/curated/en/662151561519903537/pdf/Disclosable-Version-of-the-ISR-CO-Rio-Bogota-Environmental-Recuperation-and-Flood-Control-Project-P111479-Sequence-No-17.pdf

World Bank. (2019b). Yangtze River Basin water quality management and pollution control strategy. Washington, DC: World Bank Group. Retrieved from https://documents.worldbank.org/en/publication/documents-reports/documentdetail/yangtze-water-quality-management

World Economic Forum (WEF) (2023). *It's time to recognise the economic value of an ecosystem*. Retrieved from https://www.weforum.org/stories/2023/02/an-ecosystems-economic-value-can-now-be-measured-heres-how

World Health Organization (WHO). (2023). *Drinking-water* [Fact sheet]. Retrieved from https://www.who.int/news-room/fact-sheets/detail/drinking-water

World Wide Fund for Nature (WWF). (2010). Babina and Cernovca islands: From abandoned polders and fish farms to rich wetlands in Romanian Danube Delta. *WWF Factsheet*. Danube Delta National

Institute, the Danube Delta Biosphere Reserve Administration and WWF, September. Retrieved from https://wwfint.awsassets.panda.org/downloads/wwf_factsheet_ldgc_deltaro.pdf.

World Wide Fund for Nature (WWF). (2020). *Living Planet Report 2020: Bending the curve of biodiversity loss – A deep dive into freshwater*. WWF International. Retrieved from https://wwfin.awsassets.panda.org/downloads/lpr_2020___deep_dive_into_freshwater.pdf

World Wide Fund for Nature (WWF). (2023). The high cost of cheap water: The true value of water and freshwater ecosystems to people and planet (Report prepared by Dalberg Advisors; Wijnand DeWit, Julia Lawson-Johns, Felina Lottner & Jean-Charles Guinchard, Authors). WWF International. Retrieved from https://wwfint.awsassets.panda.org/downloads/wwf-high-cost-of-cheap-water–final-lr-for-web-.pdf

World Wide Fund for Nature (WWF). (2024). *Living Planet Report 2024: A system in peril*. WWF International. Retrieved from https://www.worldwildlife.org/publications/2024-living-planet-report

Wu, Y., Zhang, R., MacDougall, A.S., Tian, D., Wang, J. & Niu, S. (2025). Wetland restoration Is effective but insufficient to compensate for soil organic carbon losses from degradation. *Global Ecology and Biogeography*, 34:e70063, https://doi.org/10.1111/geb.70063.

Xu, S., Liu, X., Li, X. & Tian, C. (2019). Soil organic carbon changes following wetland restoration: A global meta-analysis. *Geoderma*, 353, 89-96. https://doi.org/10.1016/j.geoderma.2019.06.027.

Yang, B., Yuan, X., Tang, F. & Liu, D. (2024). Small wetlands: Critical to flood management. *Science*, 386(6724), 859. https://doi.org/10.1126/science.ads2055

Yi, H., Wang, Y., Lou, Y. & Han, X. (2023). Effects of vegetation restoration on the hydrological regimes of the Chinese Loess Plateau: A comparative analysis of forested and less-forested catchments. *Forests*, 14(6), 1199. https://doi.org/10.3390/f14061199

Zhang, S., Zhang, P., Pan, B., Zou, Y., Xie, Y., Zhu, F., Chen, X., Li, F., Deng, Z., Zhang, H. & Yang, S. (2021). Wetland restoration in the East Dongting Lake effectively increased waterbird diversity by improving habitat quality. *Global Ecology and Conservation*, 27, e01535. https://doi.org/10.1016/j.gecco.2021.e01535.

Zhang, Y., Zhang, X., Fang, W., Cai, Y., Zhang, G., Liang, J., Chang, J., Chen, L., Wang, H., Zhang, P., Wang, Q. & Zhang, Y. (2025). Carbon sequestration potential of wetlands and regulating strategies response to climate change. *Environmental Research*, 269, 120890. https://doi.org/10.1016/j.envres.2025.120890.

Zou, J., Ziegler, A.D., Chen, D., McNicol, G., Ciais, P., Jiang, X., Zheng, C., Wu, J., Wu, J., Lin, Z., He, X., Brown, L.E., Holden, J., Zhang, Z., Ramchunder, S.J., Chen, A. & Zeng, Z. (2022). Rewetting global wetlands effectively reduces major greenhouse gas emissions. *Nature Geoscience*, 15, 627–632. https://doi.org/10.1038/s41561-022-00989-0.

Appendix A – Quick Scoping Review Methodology

Conceptual model

Figure 2. Conceptual framework for freshwater ecosystem restoration

Large-scale restoration of rivers and wetlands is expected to set in motion a chain of positive ecological changes that yield wide-ranging benefits. In our conceptual model, specific restoration interventions – such as re-connecting rivers to their floodplains, re-wetting drained peatlands, replanting or rewilding riparian zones, and re-establishing natural flow regimes – directly improve the ecosystem state. These actions restore hydrological connectivity, natural flow patterns, water retention, and habitat structure in freshwater ecosystems. As a result, ecological functions rebound: wetlands regain their capacity to filter water and store carbon, rivers rebuild channel complexity that supports biodiversity, and floodplains recover their ability to buffer floods.

In turn, these biophysical improvements lead to enhanced ecosystem services that benefit society. For example, a healthier river-wetland system provides cleaner water, increased carbon sequestration, better flood regulation, improved fisheries and food provision, and habitat for biodiversity. Many of these services translate into tangible social and economic benefits: reduced water treatment costs, mitigated flood damage, climate change mitigation and adaptation, food and water security for communities, and opportunities for tourism and sustainable livelihoods. The trade-offs are also acknowledged in this model – for instance, restoring natural flooding regimes might require land use changes or reduced water allocations for agriculture, posing immediate challenges that must be balanced against long-term gains.

Policy feedback and global targets: The conceptual model also recognizes an interaction with policy and international targets. The societal benefits arising from restoration support and reinforce policy goals under global agreements (e.g. climate mitigation commitments under UNFCCC through carbon storage, biodiversity targets under the CBD via habitat restoration, disaster risk reduction targets under the Sendai Framework through flood control, and wetland conservation goals under Ramsar). In essence, the restoration interventions serve to achieve these international environmental targets, while the existence of those targets and commitments in turn provides political impetus and resources for restoration activities. The evidence review will explicitly map the identified benefits (and any trade-offs) against the outcomes sought by key global frameworks to illustrate how large-scale freshwater restoration contributes to meeting international goals. This is intended to ensure the review remains relevant to decision-makers, by highlighting not only the direct benefits of restoration interventions but also their significance in the context of global environmental and development objectives.

Primary question

What is the evidence of societal benefits and trade-offs associated with large-scale river and wetland restoration?

To address this primary question, the review will consider the following elements (PICO framework):

- **Population (P):** Freshwater ecosystems – specifically **rivers and wetlands** (including floodplains, peatlands, and lakes). These represent the target ecosystems of the restoration efforts under consideration.
- **Intervention (I): Large-scale restoration interventions** in these freshwater systems. This includes actions such as reconnection of rivers to floodplains, rewetting of drained wetlands and peatlands, revegetation or reforestation of riparian zones, removal of obstructions or dams where appropriate, addressing point and non-point source pollution, and re-establishment of environmental flows or more natural hydrological regimes. The focus is on comprehensive or landscape-level restoration efforts rather than small, localized projects, in order to capture broad-scale ecological recovery.
- **Control/Comparator (C): Degraded or unrestored conditions** as the baseline. Comparators may include the state of the ecosystem before restoration, or similar ecosystems/areas that remain degraded or modified (e.g. channelized rivers, drained wetlands, disconnected floodplains). In assessing evidence, studies should compare outcomes post-restoration against those in non-restored scenarios to isolate the effects of restoration.
- **Outcome (O): Ecosystem service improvements and societal benefits** resulting from restoration, as well as any associated trade-offs. Key outcomes of interest include improved water quality, enhanced flood mitigation and water regulation, increased carbon sequestration and climate regulation, biodiversity recovery, and benefits to human livelihoods such as food security (e.g. improved inland fisheries or agriculture), water security (reliable water supply), and socio-economic wellbeing (e.g. income from fishing or ecotourism). Outcomes will also encompass any trade-offs or unintended consequences, such as losses in land productivity, changes in water allocation affecting certain user groups, or other costs.

Secondary questions

In addition to the primary question, the review will explore the following secondary questions:

- **Effectiveness of restoration approaches in different contexts:** *What types of restoration approaches are most effective under different climatic and socio-political conditions and at what scales?* – This question will examine whether certain restoration strategies (e.g. floodplain reconnection, wetland rewetting, etc.) yield greater benefits in particular environments. We will consider how factors like climate zone (arid vs. tropical, etc.), governance context, stakeholder engagement, or socio-economic setting influence the success and outcomes of restoration. This could highlight, for instance, that wetland rewetting has especially high carbon benefits in temperate peatlands, or that community-led river restoration in certain socio-political settings leads to better livelihood outcomes, etc. We will also consider the importance of undertaking activities at the appropriate scale, noting that the study is focussed on large-scale restoration. Understanding context-dependent effectiveness will help tailor future restoration efforts to local conditions.
- **Trade-offs and unintended impacts:** *What trade-offs have been observed alongside the benefits of large-scale restoration (e.g. loss of productive land, altered water allocations)?* – This question focuses on the documented trade-offs, conflicts, or negative outcomes that can accompany restoration projects. Examples might include the loss of agricultural land when floodplains are reactivated (trade-off between flood mitigation and farming), changes in flow regimes that affect upstream or downstream water users, potential displacement or changes in resource access for local communities, or ecological trade-offs like favouring one species/habitat over another. Restoration activities may also involve trade-offs between potential benefits: for example, measures that restore certain types of habitats may also result in increased

greenhouse gas emissions. By synthesizing evidence of these trade-offs, the review will provide a nuanced perspective on restoration – acknowledging challenges such as short-term socio-economic costs or adjustments – and identify how such trade-offs have been managed or mitigated in various cases.

These secondary questions complement the primary question by addressing "what works where" and "what are the downsides", thereby offering practical insights for implementing restoration under different conditions and ensuring that benefits are maximized while downsides are minimized.

Scope of the work

This review will maintain a broad scope in terms of geography and context, while applying specific inclusion criteria to focus on relevant ecosystems and outcomes. Key scope parameters include:

- **Geographic scope: Global** – The review will include evidence from all regions of the world. There are no geographic exclusions; studies and case examples from any country or continent will be considered, as long as they pertain to river or wetland restoration. This global scope is appropriate given that the Freshwater Challenge is an international initiative and seeks broadly applicable insights.
- **Climatic scope: All climate zones** – Restoration projects in arid, semi-arid, temperate, tropical, and coastal climates will all be included. The intention is to capture evidence across diverse environmental settings to see how outcomes may vary with climate. No climate zone is excluded.
- **Language: English only** – The review will search and include literature published in English. Due to resource and time constraints, non-English sources will not be considered.
- **Time frame (publication dates): 2005 – 2025** – We will include studies published roughly in the last 20 years (January 2005 up to the search date in 2025). This date range ensures that the evidence is relatively up-to-date and relevant to current restoration practices and contexts, while long enough to cover significant restoration initiatives and their observed outcomes.
- **Population scope (ecosystem types): Rivers and wetlands**– The review is restricted to freshwater ecosystems inland or connected to river systems. This includes rivers and streams (and their floodplains) and inland wetlands (marshes, peatlands, swamps, and lakes). We will exclude studies focused solely on deltas/mangroves or marine/coastal ecosystems. This ensures relevance to the Freshwater Challenge targets. The scope does not include terrestrial restoration except where it directly ties into river/wetland systems, e.g. reforestation in a watershed to benefit river health.
- **Intervention scope (types of interventions)**: The review will be focussed on large-scale interventions. As noted above, the focus is on comprehensive or landscape-level restoration efforts rather than small, localized projects.
- **Outcome scope (types of outcomes/evidence):** The review will include only studies that provide evidence of societal benefits and/or trade-offs resulting from the restoration. In practice, this means included sources must report on changes in ecosystem services or human well-being indicators post-restoration (e.g. water quality improvements, flood risk reduction outcomes, carbon stock changes, fishery yields, community livelihood impacts, etc.). Studies that examine ecological or hydrological changes without linking them to societal benefits may be considered only if a clear inference to an ecosystem service can be made, but purely ecological metrics (like species diversity) will not be the sole reason for inclusion unless tied to a benefit of interest (e.g. biodiversity as a benefit in itself or as a proxy for ecosystem health). This criterion ensures the review remains focused on the "so what for society" aspect of restoration. The review will also consider any economic assessments of the benefits related to restoration. Both positive outcomes and negative outcomes (trade-offs, conflicts) are of interest.

Other restrictions: No further restrictions by study design are imposed at this stage – we expect to include a mix of empirical studies, modelling studies, case study reports, and relevant review papers as long as they meet the above criteria.

Potential keywords

To systematically search for relevant literature, we will develop search strings drawing from a range of keywords related to the Population, Intervention, Comparator, and Outcome (PICO elements), as well as broader context terms. Some initial potential keywords (to be combined in various ways for database searches) include:

- **Population terms:** *river*, *wetland*, *freshwater*, *floodplain*, *peatland, lake* – (These terms capture the ecosystem types of interest. We will also consider plural forms and specific sub-types like *marsh*, *swamp*, *stream* if needed.)
- **Intervention terms:** *restoration*, *rewilding*, *rewetting*, *revegetation*, *flow restoration*, *rehabilitation*, *ecosystem recovery*, *nature-based solution*, *policy*, *regulatory* – (These terms describe the actions or approach. This includes non-structural interventions, such as changes to regulatory settings that are intended to improve the function of freshwater systems. We will use synonyms to ensure we capture literature that might call it "rehabilitation" or "ecological restoration" etc.).
- **Intervention scope**: *large-scale, landscape-scale, catchment-scale, basin-scale, regional-scale, ecosystem-scale, watershed-scale, broad-scale* – (These terms narrow the search to only capture large-scale initiatives, and to exclude local, small-scale restoration projects.)
- **Comparator terms:** *degraded*, *modified*, *unrestored*, *baseline*, *pre-restoration* – (These help in searches to ensure we find studies that compare restored vs. degraded conditions or before/after. For example, "wetland restoration impact vs baseline" or "restored river compared to degraded".)
- **Outcome terms:** *ecosystem services, carbon sequestration, carbon storage, biodiversity, water quality, water purification, flood control, flood mitigation, food security, water security, livelihoods, fishery, climate adaptation, trade-offs, benefits* – (These terms target the benefits we are interested in. We will mix and match, e.g., "wetland restoration" AND "flood control", or "river rehabilitation" AND "water quality improvement", etc. Trade-off terms ensure we capture papers discussing conflicts or negative outcomes.)
- **Other context terms:** *SDG* (Sustainable Development Goals), *Ramsar*, *CBD* (Convention on Biological Diversity), *UNFCCC* (climate convention), *UNCCD* (desertification convention), *climate change adaptation*, *policy*, *framework* – (These terms may be used to capture grey literature or policy-oriented documents or to filter results relevant to international initiatives. They will be used sparingly and likely in targeted searches of organizational websites or Google, rather than in academic databases, except where relevant in article text or titles.)

Search string construction: These keywords will be combined into search strings using Boolean operators. For example: (river OR wetland OR floodplain) AND (restoration OR rewilding OR rehabilitation) AND (benefits OR "ecosystem services" OR trade-offs) as a generic template, with variations to capture specific outcomes (e.g. replacing "benefits" with specific services like "carbon" or "flood"). We will refine the strings to balance sensitivity (catching many results) vs. specificity (relevant results).

Potential search locations

Given the interdisciplinary nature of this topic (ecology, hydrology, climate, development) and the mix of academic and grey literature, the search will span multiple types of sources.
Potential search locations include:

- **Peer-reviewed literature databases:** We will search the following academic databases: *Web of Science* and *Google Scholar*.
- **Grey literature and organizational reports:** To capture case studies and data not published in journals, we will search the websites and libraries of key organizations and initiatives. This includes conservation NGOs and international bodies such as the Ramsar Convention, UNEP, Wetlands International, IUCN, The Nature Conservancy (TNC), WWF, the World Bank, and relevant UN agencies or convention secretariats. We will use targeted Google searches with operators like site:org, site:gov, site:int and filetype filters (e.g. filetype:pdf) to find reports, policy briefs, or conference documents. Grey literature is crucial for this topic because many large restoration projects report outcomes in reports or evaluations rather than journal articles.
- **Unpublished data:** *Not included.* This QSR will not actively seek out unpublished data or confidential project documents, nor conduct interviews for expert evidence.
- **Inclusion of existing reviews or theoretical studies:** We will include other review papers, syntheses, or relevant conceptual studies if they directly address restoration benefits or trade-offs. For example, if there are systematic reviews on wetland restoration and ecosystem services, or meta-analyses of river restoration outcomes, these will be valuable sources to incorporate (both for their findings and as pointers to primary literature we might have missed). We will also include high-level reports or theoretical frameworks that synthesize knowledge of freshwater restoration (even if not new primary data) because they can provide important insights or summary of evidence. We will, however, ensure that the QSR's conclusions are based on evidence and not just opinions from conceptual papers.

(Search process note: We plan to start with an initial "long list" of literature already assembled by WWF-UK and then expand using snowball techniques (looking at references of references) as well as the above systematic searches in databases and websites. The search strategy will be documented in the final report appendix, showing how each database was queried and how many results were screened from each source. All search locations and keywords will be finalized in consultation with the project team during the inception phase.)*

Appendix B – Water supply benefits from freshwater ecosystem restoration

Source	Restoration measure	Location	Scale	Water supply benefit	Additional information
Global					
Kebede et al. (2024)	Managed aquifer recharge, wetland restoration, and infiltration basins	Global review (India, USA, Africa)	Regional	**Increased groundwater recharge** (F2) – 200-500 mm/year of additional groundwater recharge from infiltration basins and wetland restoration.	Review of global case studies demonstrated substantial increases in recharge from infiltration basins and wetland restoration.
Africa					
Ilstedt et al. (2016)	Reforestation of tree cover	Burkina Faso, West Africa	Local catchment	**Increased baseflows** (F1) & **groundwater recharge** (F2) – study demonstrated that reforestation at the optimal density results in improved recharge and flows	Field experiments showed groundwater recharge was maximized at intermediate tree density. Moderate forest cover increased recharge and improved dry-season baseflows.
Marais & Wannenburgh (2008)	Removal of invasive alien trees from the riparian zone	Western Cape, South Africa	Regional	**Increased water yield** (F1) +34.4 million m³/year streamflow gain (~42% of a new dam's yield) at less than 20% of the per-unit cost for a new dam.	Program across multiple catchments improving the riparian zone, primarily through removal of invasive *Accacia spp*.
Meaza et al. (2022)	Catchment soil and water conservation (terraces, bunds)	Ethiopian highlands	Multiple catchments	**Increased baseflow** (F1) & **groundwater recharge** (F2): runoff reduced 40%, water table in wells rose from ~18 m to ~2 m depth after restoration	Analysis using metadata from 106 peer-reviewed journal articles looking at 361 paired-catchment cast-studies.
TNC (2015)	Modelled outcome of watershed rehabilitation (reforestation, terracing, farm BMPs)	Tana River, Kenya	Basin scale	**Increased water yield** with potential ~4% increase in annual yield & **increased base flow** potential for up to +15% flow in dry season (F1)	Study assessed potential benefits if investment was made in restoration measures

Source	Restoration measure	Location	Scale	Water supply benefit	Additional information
Asia					
Asian Development Bank (2022)	Catchment restoration (reforestation, recharge ponds)	Nepal	Multiple mountain catchments	**Increased water yield** (F1) & **groundwater recharge** (F2) with yields increased by ~75%. Resulted in over 50,000 households with improved domestic and irrigation water sources. Time to collect household water during the dry season cut by 73%.	Restored hillsides and recharge structures increased spring and stream yields
Dashora et al. (2018)	Check dams (recharge structures)	Rajasthan, India	4 small catchment dams	**Improved groundwater recharge** (F2) – additional ~33 mm of groundwater recharge in an average rainfall year and 17 mm in a drought year. Equates to ~743,000 m³/year, which supported ~16% of winter crop production.	Study of recharge associated with 4 check-dams. Over 200,000 small earthen check-dams in India have been built to recharge aquifers.
Yi et al. (2023)	Vegetation/land cover restoration	Loess Plateau, China	Multiple catchments	**Increased baseflow** (F1) – contribution of baseflows to overall stream flow was ~60% in restored catchments, compared to ~32-43% in degraded catchments.	Assessments looked at impact 20+ years of revegetation. Found annual storm runoff declined while baseflow trends increased, non-flood season baseflows rose as stormflows fell.
North America					
Cowdery et al. (2019)	Wetland and prairie restoration (farmland conversion)	Minnesota, USA	Local catchment	**Increased baseflows** (F1) with baseflow fraction of total flow increased from 25% to 35% & **groundwater recharge** (F2) with recharge rates increased by 16%	US Geological Survey assessment of the largest US wetland and prairie restoration, the Glacial Ridge National Wildlife Refuge.
Hunt et al. (2018)	Meadow re-watering (pond-and-plug[3])	Sierra Nevada, California, USA	Single meadow	**Increased baseflows** (F1) - Summer baseflow increased 5–12 times & **groundwater recharge** (F2)	During major drought summer baseflow still at least five times greater than before restoration. Groundwater levels rose at four out of five sites.
Westbrook et al. (2006)	Beaver dam reintroduction	Rocky Mountains, Canada	Reach-scale beaver ponds	**Increased baseflows** (F1) & **groundwater recharge** (F2) - ponded water behind beaver dams increases groundwater recharge and augments stream baseflows during low-flow periods	Beaver dams raise water levels and promote infiltration.

---

[3] Pond-and-plug is a method of restoring incised stream channels in degraded meadows by excavating "ponds" in the adjacent floodplain to create borrow pits; using the excavated material ("plug") to fill sections of the eroded or incised stream channel; and redirecting flow into remnant or constructed shallow channels

Appendix C – Water quality benefits associated with freshwater ecosystem restoration

Source	Restoration measure	Location	Scale	Water quality benefit	Additional information
Global					
Kaiser et al. (2020)	Multiple river restoration methods	Global review (not Africa)	Various	**Improved water quality** (F3) – 80% of projects reviewed demonstrated enhanced ecosystems services, specifically improved water quality and retention of nutrients	Reviewed 88 projects globally for demonstrated improvement in provision of ecosystem services following restoration. Found high level of confidence in results related to improved water quality.
McCrackin et al. (2017)	Nutrient load reduction in eutrophic lakes	Global meta-analysis	Various	**Improved water quality** (F3) – water quality in ~34% of freshwater systems returned to baseline conditions once anthropogenic nutrient sources were removed	Lakes can take decades to recover once nutrient loads are reduced/removed.
Russi et al. (2013)	Wetland restoration & conservation	Global	Various	**Improved water quality** (F3) – Enhanced water quality, reduced turbidity, nutrient removal	Provides a range of global case studies.
Africa					
Emerton et al. (1999)	Protect & manage Nakivubo Wetland for wastewater treatment	Kampala, Uganda	Local, urban wetland	**Improved water quality** (F3) – Reduced nutrient load, improved water quality. **Reduced water treatment costs** (F4) & i**mproved drinking water** (F5) - US$1–1.75 million/year in avoided treatment costs	Improved water quality entering Lake Victoria.
The Nature Conservancy (2015)	Watershed rehabilitation (reforestation, terracing, farm BMPs)	Tana River, Kenya	Basin scale	**Improved water quality** (F3) – Greater dry-season flow to help lessen concentrations of pollutants. **Reduced water treatment costs** (F4) & **improved drinking water** (F5) Approximately US$250,000 in cost savings a year from avoided filtration, lowered energy consumption, reduced sludge disposal costs	Study was part of a business case to support establishing a Tana-Nairobi water fund. Identified potential for improved water quality to decrease waterborne pathogens for more than half a million people.
Asia					
Gurung (2007)	Community-led catchment restoration	Lake Rupa, Nepal	Local, lake catchment	**Improved water quality** (F3) – Increased dissolved oxygen, reduced eutrophication, invasive aquatic	Focus on small lakes

Source	Restoration measure	Location	Scale	Water quality benefit	Additional information
	(reforestation, check-dams)			weed reduced from ~90% to ~10%. Improved fisheries.	
Europe					
Audet et al. (2020)	Wetland restoration (shallow lakes and fens)	Denmark	Wetland size from 6 to 913 ha	**Improved water quality** (F3) - All restored wetlands removed total N (42–305 kg N ha^{-1} year^{-1}), while some wetlands acted as source of total P and others as a sink (- 2.8 to 10 kg P ha^{-1} year^{-1}).	Monitored outcomes from eight restored wetlands located in agricultural catchments. Confirms that wetlands can remain a source of P several years after restoration
Mrozińska et al. (2018)	Stream habitat restoration (re-meandering)	Kwacza River, Poland	Local river	**Improved water quality** (F3) – 70% nitrate, 50% ammonium reduction, dissolved O_2 increase.	
Pedersen et al. (2007)	Re-meandering of Skjern River and floodplain reconnection	Skjern River, Denmark	Basin scale	**Improved water quality** (F3) – Annually traps 5–10 tonnes P, 200 tons N; reduced nutrient transport by 5–10%	Improved estuarine water quality
Puttock et al. (2018), White et al., (2025)	Beaver reintroduction	United Kingdom	Regional catchments	**Improved water quality** (F3) – Nutrient, sediment retention, improved water clarity and i**mproved drinking water** (F5) – reduction in E. Coli	
van Leeuwen et al. (2021)	Island wetland construction	Markermeer Lake, Netherlands	Local	**Improved water quality** (F3) – Reduced turbidity, improved water clarity, reduced sediment resuspension	
North America					
Hansen et al. (2018)	Wetland restoration in agricultural watersheds	Midwestern U.S.	Regional	**Improved water quality** (F3) – Nitrate load reduction, nutrient interception.	Wetlands five-times more efficient per unit area at reducing nitrate concentrations compared with the best agricultural management strategies.
National Academies of Sciences, Engineering, and Medicine. (2020)	Forest, wetland, stream restoration	Catskill–Delaware catchment, New York City, USA	Catchment	**Improved water quality** (F3) – Reduced microbial/nutrient contamination. **Reduced water treatment costs** (F4) & i**mproved drinking water** (F5) - avoided need for $8-10 billion filtration plant and $365 million/year treatment costs.	Ongoing exemption from EPA requirements for filtration.

Source	Restoration measure	Location	Scale	Water quality benefit	Additional information
TNC Iowa (2021)	Oxbow wetland reconnection	Iowa, U.S.	State-wide/localized	**Improved water quality** (F3) – ~62–100% nitrate removal, visibly reduced turbidity.	
Williams & Turner (2015)	Watershed remediation of acid mine drainage	Pennsylvania, U.S.	Local catchment	**Improved water quality** (F3) – Improved water chemistry: increased pH, 68% reduction in sulphates and 90% reduction in iron	
Oceania					
Paul et al. (2018); Waltham et al. (2019); DCCEEW, (2023)	Riparian replanting, constructed wetlands in sugarcane floodplain	Great Barrier Reef catchment, Australia	Basin scale	**Improved water quality** (F3) – Improved dissolved oxygen, reduced nutrients/sediments runoff. Total of 140,000 tonnes of fine sediment and 550 tonnes of dissolved inorganic nitrogen stopped from entering the Reef between 2014 and 2022	
South Australia EPA (2008), Bryan et al., (2009)	Fencing streams, revegetating riparian corridors, controlling weeds and erosion	Myponga catchment South Australia	Catchment	**Improved water quality** (F3), r**educed water treatment costs** (F4) & i**mproved drinking water** (F5) - reduced sediment (12%) and microbial contamination (potential reduction of 93% of *Cryptosporidium* associated with exclusion of dairy calves.)	Findings based on modelling of a combination completed restoration measures plus potential outcomes from additional restoration.
Walsh et al. (2022)	Green stormwater infrastructure	Melbourne, Australia	Local, urban catchment	**Improved water quality** (F3) – Lower pollutant loads, 5°C stream temperature reduction	
Wilcock et al. (2013)	Catchment best-management, riparian fencing	Waikato, New Zealand	Catchment	**Improved water quality** (F3) – Reduced sediment, bacteria, improved clarity	Assessed 5 streams in catchments with pastoral dairy farming.

Appendix D – Flood risk reduction associated with freshwater ecosystem restoration

Source	Restoration measure	Location	Scale	Flood regulation benefit	Additional information
Global					
Vicarelli et al. (2024)	Various NbS for flood mitigation (e.g. wetland restoration, forest conservation)	Global	Various	**Attenuation of flood peaks and cost-effective flood management** (F6) – 71% of studies found to be cost-effective for disaster risk reduction	Systematic review of >20,000 studies worldwide. Most frequently effective interventions involved wetlands, forests, and other ecosystem restorations.
Yang et al. (2024)	Management and restoration of small wetlands	Global	Various	**Attenuation of flood peaks and cost-effective flood management** (F6) –surface runoff reduced by 15-30% and flood peak levels decreased by 10-25%	Small wetlands absorb 50 – 70% of rainfall thereby lowering the risk of mountain floods and debris flows.
Serra-Llobet et al. (2022)	Floodplain reconnection projects (levee setbacks and multi-benefit floodplain restoration)	USA and Germany	River reach (Two rivers in California, USA and two in Germany)	**Attenuation of flood peaks and cost-effective flood management** (F6). Levee setback resulted in 50cm decrease in flood peak (Elbe River)	Concluded that projects integrating flood risk reduction with ecosystem restoration are often cost-effective, with multiple benefits (flood risk reduction, ecosystem benefits, improved recreation).
Asia					
Pittock & Xu (2011)	Setback/removal of levees, restoration of wetlands, upstream reforestation	China	Basin scale (Yangtze)	**Attenuation of flood peaks and cost-effective flood management** (F6) – additional 2,9700 km^2 floodplain restored with a floodwater retention capacity of 8 billion m^3	
Europe					
Dixon et al. (2016)	Modelled benefits of flood reduction from floodplain forest restoration	UK	Sub-catchment	**Attenuation of flood peaks and cost-effective flood management** (F6). Floodplain forest restoration at the sub-catchment scale with 10–15% of the catchment restored led to reductions of up to 6% in peak discharge. Restoring 22-	Long time lags to achieve the reductions – up to 25 years of forest growth.

Source	Restoration measure	Location	Scale	Flood regulation benefit	Additional information
				47% of channel network led to 10% reduction.	
Dottori et al. (2023)	Modelled benefit of detention areas (designated flood storage basins to reduce peak flows)	Continental (Europe)		**Attenuation of flood peaks and cost-effective flood management** (F6) & **reduced flood damages** (F7) – projected a 8-% reduction in flood losses yielding about €4 in benefit for each €1 spent.	Modelling considered a high warming scenario (~3°C). Creating flood storage areas reduced projected European flood losses by ~80% (from €44 billion to €8.1 billion/year) and flood exposure by ~84%.
Klijn et al. (2018)	Setback of levees to provide more space for the river	Netherlands	Catchment (Rhine & Meuse Rivers)	**Attenuation of flood peaks and cost-effective flood management** (F6) – set back resulted in lowering of the 1:1250 per year flood levels by 0.3 m.	Involved 30 interventions along three Rhine River branches, adding 4,400 ha of floodplain area.
Logar et al. (2019)	Economic assessment of river restoration (channel re-naturalization, habitat and flow restoration)	Switzerland	Local: 2 case studies with results extrapolated nationally	**Attenuation of flood peaks and cost-effective flood management** (F6) – positive cost-benefit analysis of restoration	Cost–benefit analysis found restoration benefits exceeded costs. Local residents' willingness-to-pay for restored rivers (e.g. improved flood safety) was higher than actual project costs.
Nilsson et al. (2018)	Range of measures including re-meandering, addition of word, removal of dams, installing new floodplains, revegetation	Nordic countries	Various	**Attenuation of flood peaks and cost-effective flood management** (F6) – increased water retention through restoration of floodplain, instream channel, and/or upland areas.	Synthesis of studies across the five Nordic countries of river restoration case studies focussed on improved flood management
Puttock et al. (2021)	Beaver reintroduction	United Kingdom	Regional catchments	**Attenuation of flood peaks and cost-effective flood management** (F6) – reintroduction of beavers attenuated average flood flows by ~60%	
North America					
Hey et al. (2004)	Modelled floodplain wetland reconnection	Upper Mississippi, USA (multi-state)	Basin	**Attenuation of flood peaks and cost-effective flood management** (F6) – potential to store ~48 billion m^3 of floodwater **Reduced flood damages** (F7) - avoided an estimated $16 billion in flood damages.	Modelled the potential benefits of restoring lost floodplains in the Upper Mississippi Basin.

Source	Restoration measure	Location	Scale	Flood regulation benefit	Additional information
Javaheri & Babbar-Sebens (2014)	Modelled simulation of the benefits of wetland construction and restoration	Indiana watershed, Midwest USA	Catchment	**Attenuation of flood peaks and cost-effective flood management** (F6) – modelling suggested wetlands would reduce peak flows by up to 42%, cut flooded area up to 55%, and lower flow velocities ~15%.	Deeper wetlands yield larger reductions (e.g. 500-year flood peak cut by 20%).
Johnson et al. (2020)	Floodplain land acquisition and conservation (preventing development in flood-prone areas)	USA	National	**Attenuation of flood peaks and cost-effective flood management** (F6) & **Reduced flood damages** (F7) - $1 invested in floodplain restoration today avoids about $5 in future flood losses	Conserving natural floodplains can yield high net benefits by avoiding future damages. Land conservation is more cost-effective than paying for repeat flood damages, especially in frequently flooded zones.
Liao et al. (2020)	Beaver pond restoration (simulated)	Milwaukee River, USA	Catchment	**Attenuation of flood peaks and cost-effective flood management** (F6) - peak flows in major rainstorms dropped by 15–45%	Modelling of beaver reintroduction suggests that networks of beaver dams could significantly reduce downstream flood peaks.
South America					
World Bank (2019a), World Bank (2009)	Floodplain and channel restoration (channel widening, meander restoration, levee setback)	Bogota, Colombia	Urban river	**Attenuation of flood peaks and cost-effective flood management** (F6) – flood risk along 68 km of Bogota river improved to 100-year flood-standard protection, 1.19 million people under reduced flood risk	Hybrid nature-based and engineered project, including habitat restoration, wastewater treatment enhancement, hydraulic reconnection, and creation of multifunctional green spaces.

Appendix E – Carbon storage and GHG benefits associated with freshwater ecosystem restoration

Source	Restoration measure	Location	Scale	Carbon storage & GHG flux benefit	Supporting evidence
Global					
Leifeld & Menichetti (2018)	Peatland rewetting	Global	Global	Rewetting prevents major carbon losses and secures long-term CO_2 storage.	Literature review and modelling mapped global peatland extent and restorable area. Compared carbon loss under continued drainage with avoided emissions under rewetting. Identified rewetting as an effective mitigation pathway.
Darusman et al. (2020)	Peatland rewetting	Global (temperate, tropical, boreal zones)	Meta-analysis of 28 studies (48 CO_2, 67 CH_4, 5 DOC effect sizes)	Rewetting cuts CO_2 emissions but raises CH_4, especially in the first years; DOC remains stable.	Meta-analysis of paired plots across climate zones. Quantified CO_2 reductions, strongest in temperate regions. CH_4 rose most sharply in the first four years. DOC showed minimal change.
Günther et al. (2020)	Rewetting scenarios (immediate, delayed, partial, none)	Global	Global Peatland Database	Long-term CO_2 savings from rewetting exceed temporary CH_4 increases.	Modelled five management pathways and compared radiative forcing of CO_2, N_2O, and CH_4. Found that delayed or partial rewetting reduced climate benefits relative to immediate action.
Wu et al. (2025)	Passive and active wetland restoration (rewetting, vegetation management, soil amendments)	Globally distributed sites	Global	Passive restoration increased SOC by 141% in degraded sites versus 8% with active measures; inland wetlands showed 118% SOC increase. Gains levelled off after ~10 years and rarely matched natural wetlands.	Meta-analysis of global literature comparing restored, degraded, and natural wetlands. SOC in restored wetlands (44.6 g kg^{-1}) was higher than degraded (24.9 g kg^{-1}) but lower than natural (88.6 g kg^{-1}).
Xu et al. (2019)	Peatland rewetting	Northern Hemisphere	Global	SOC in restored wetlands exceeded cultivated sites but remained below natural wetlands. Best recovery occurred in temperate, seasonal hydrology sites restored for 6–10 years.	Meta-analysis of 41 studies comparing restored, cultivated, and natural wetlands. SOC was 13.8% higher than cultivated wetlands but 29.2% lower than natural wetlands. Recovery improved with limited cultivation (<15 years pre-restoration).

Source	Restoration measure	Location	Scale	Carbon storage & GHG flux benefit	Supporting evidence
He et al. (2024)	Wetland rewetting	Globally distributed sites	Global	Restoration reduced global warming potential of wetlands by 62%, shifting sites from CO_2 sources to sinks within ~4 years. CH_4 emissions increased but were outweighed by CO_2 uptake and lower N_2O.	Meta-analysis of 253 studies. Restoration raised CH_4 by 544%, lowered N_2O by 69%, and enhanced CO_2 uptake. Transition to net CO_2 sink occurred after ~4 years.
Bianchi et al. (2021)	Rewetting agricultural sites (natural wetting, *Sphagnum* paludiculture, emergent-crop paludiculture)	Temperate and boreal regions	Sub-global	Rewetting restored CO_2 sinks, though sites remained small net GHG sources. Sphagnum cultivation acted as CO_2 sinks when harvest excluded, while emergent-crop systems were net GHG sources.	GHG balances differed among restoration, Sphagnum farming, and emergent crops. N_2O was higher in restoration and emergent sites than in *Sphagnum* systems.
Taillardat et al. (2020)	Freshwater wetland restoration	Freshwater marsh projects in developed nations	Global (24 studies; 23 freshwater projects)	Inland wetland restoration provides net climate cooling at 10–100 year time scales but is ineffective for short-term mitigation.	Cost-effectiveness analysis of 24 studies. Project costs varied (marsh US\$71,221 ha^{-1} yr^{-1}, floodplains US\$20,948 ha^{-1} yr^{-1}, peatlands US\$1,229 ha^{-1} yr^{-1}). Cost-effectiveness ranged US\$4,200–49,200 per tonne C yr^{-1}.
Zou et al. (2022)	Wetland rewetting	Global (mainly Asia, Europe, North America)	Global	Without restoration, wetlands could emit ~408 Pg CO_2e by 2100. Rewetting offsets CH_4 and N_2O forcing through enhanced CO_2 uptake.	Modelled scenarios using a global GHG flux database. Rewetting reduces emissions by 249±155 Pg CO_2e (full restoration) or 156±94 Pg CO_2e (high-carbon sites) by 2100, mainly from marshes, floodplains, and peatlands.
Tölgyesi et al. (2025)	Ecosystem restoration (forests, grasslands, wetlands)	Global	Global	Wetland restoration has limited climate potential; projected mitigation close to zero when accounting for climate-driven ecosystem shifts.	Modelling predicted 2.83 million km² restorable wetland area. Maximum sequestration gain 1.92 Gt yr^{-1}, of which wetlands contributed 0.22 Gt yr^{-1} (11.4%). Model performance for wetlands was comparatively low.
Kumar et al. (2025)	Wetland restoration	Global	Global	Wetlands act as major carbon sinks but also emit CH_4. Sequestration rates vary, with swamps storing more carbon than marshes and peatlands.	Meta-analysis of carbon stock, sequestration, and emissions data. Peatlands sequestered 1.26 Mg C ha^{-1} yr^{-1}, swamps 2.17 Mg C ha^{-1} yr^{-1}, and marshes 1.80 Mg C ha^{-1} yr^{-1}.
Hashemi et al. (2025)	Restoration of High-Value Freshwater	Global	Global	Restoring 355–484 Mha could sequester 1.07–3.41 Pg CO_2 yr^{-1}, equal to 2.7–8.5% of current global emissions. Nearly half the	Modelled restoration scenarios for degraded ecosystems within HVFEs. Minimum

Source	Restoration measure	Location	Scale	Carbon storage & GHG flux benefit	Supporting evidence
	Ecosystem (HVFE) by river–floodplain reconnection, riparian forest recovery, and vegetation rehabilitation			potential lies in 49 countries in the Freshwater Challenge.	sequestration potential was equivalent to global peatland restoration.
Lal (2013)	Peatland rewetting by water table management and wetland vegetation recovery	Global	Global	Restored wetlands could sequester 1–3 Mg C ha^{-1} yr^{-1}.	Estimates synthesised from a global literature review on peatland carbon management.
Schuster et al. (2024)	Wetland restoration (peat and non-peat wetlands)	Global (mainly western Europe and North America)	Global synthesis from site data	Most restored (77%) and all natural peatlands were net sinks; most degraded peatlands (69%) were carbon sources. Non-peat wetlands showed little difference across states. Climate benefits may not align with Paris targets by 2100.	Meta-analysis of 63 studies. Restored peatlands took ~525 years and non-peat wetlands ~141 years to achieve net cooling.
Mitsch et al. (2013)	Wetland creation and restoration	Ohio (USA), Costa Rica, Botswana, and other temperate, tropical, and boreal sites	Global	Wetland creation and restoration provide long-term carbon sinks without significant warming from CH_4.	Field studies and modelling showed CH_4 becomes negligible within 300 years compared to carbon storage. Global wetlands estimated to store ~830 Pg C.
Moomaw et al. (2018)	Wetland conservation and restoration	Global	Global	Conserving and restoring wetlands maintains terrestrial carbon sinks and supports ongoing sequestration into soils and biomass.	Literature synthesis estimated that 2 million km² of new/restored wetlands (17% increase in area) would offset 1% of the annual rise in atmospheric CO_2.
Moreno-Mateos et al. (2012)	Wetland restoration and creation	12 countries	Global (401 restored, 220 created wetlands, >21,294 ha;	Restored wetlands increased carbon storage but plateaued below reference levels after ~20 years. Larger wetlands and those in warmer climates or with higher hydrologic exchange recovered faster.	Meta-analysis showed wetlands recovered to ~74% of reference biogeochemical function after 50–100 years, largely due to incomplete carbon storage recovery.

Source	Restoration measure	Location	Scale	Carbon storage & GHG flux benefit	Supporting evidence
			reference wetlands >19,694 ha)		
Asia					
Sapir et al. (2025)	The original marsh was drained in 1957 for agriculture and rewetted in the early 1990s.	Hula Valley, Israel	Individual wetland ("deep peat" area 1200 ha)	Raising of the water table around 30 years ago slowed peat degradation, reduced CO_2 emissions, and increased CH_4 and N_2O fluxes.	In the drained section, mean SOM content in the top 30 cm was 5%, while in the rewetted section it was 34%.
Li et al. (2022)	Wetland restoration	China	Country (area of potential natural wetland distribution 3.3 million km², restorable wetlands 1.0 million km²)	Wetland restoration leads to increased CH_4 emissions but also to significant CO_2 uptake, yielding a net cooling effect.	Used a biogeophysical wetland model and a climate model to evaluate potential wetland restoration impacts. Wetland restoration leads to increased CH_4 emissions (0.13 Pg CH_4 yr^{-1}) and CO_2 uptake (−1.07 Pg CO_2 yr^{-1}).
Europe					
Huth et al. (2022)	Rewetting peatland (raised bog)	Northwestern Germany	Seven experimental plots of approximately 8 × 8 m	Rewetting alone treatment reduced CO_2 emissions and increased CH_4, with overall mitigation potential varying by vegetation cover.	The study site had been drained for centuries and then restored by rewetting in 2004. Measured GHG fluxes biweekly from Sep 2017 to Dec 2019.
Mazzola et al. (2020)	Removal of forestry plantations followed by rewetting through drain blocking	Lonielist field site, RSPB Forsinard Flows National Nature Reserve, Scotland, UK	Individual peatland (within reserve of 215 ha)	The total GHG balance suggested that the whole restoration area is still a net GHG source, though rewetting reduces losses compared to drained conditions. The original peat surface was near GHG equilibrium. Ridges and furrows remaining from forestry acted as a net GHG sinks. The bog pool was a net source of greenhouse gases	During the 1970s and 1980s large areas were drained for forestry plantations. These were removed between 2000 and 2006, followed by drain blocking. Measurements of net ecosystem exchange (NEE) of CO_2, CH_4, and N_2O were done in 2017—2019.

Source	Restoration measure	Location	Scale	Carbon storage & GHG flux benefit	Supporting evidence
Schaller et al. (2022)	Peatland rewetting involving constructing dams, filling the cut-over areas with original rooted soil layer, and rewetting	Part of Diepholzer Moorniederung, the Ramsar wetland area, near Uchte, Nienburg, Lower Saxony, Germany	Individual peatland (rewetted area 19 ha)	After rewetting the site remained a net CO_2 source, with higher CH_4 fluxes, but the GHG emissions were already lower than in comparable still-drained peatlands. It will take another few decades before the peatland is a net sink of GHG.	GHG flux was measured from June 2016 to January 2018, i.e. 18 years after rewetting.
Kandel et al. (2019)	Rewetting riparian wetland and subjecting it to extensive water and vegetation management	Brynemade, River Odense, Funen, Denmark	Individual wetland	The site remained a CO_2 source during the study, mainly attributed to on-site deposition of biomass which apparently stimulated both CO_2 and CH_4 emissions. Rewetting is expected to lead to a sink over time.	GHG balance monitoring showed a net CO_2 source, with CH_4 and N_2O contributing.
Liu et al. (2020a)	Peatland rewetting scenarios with different rewetting priorities	European Union-28	Continental	From the viewpoint of GHG emissions, highly degraded peatlands provide the greatest mitigation potential if rewetted and should be restored first. Compared to no peatland restoration, rewetting of all drained European peatlands until 2050 using the suggested strategy reduces the cumulative N2O-N emissions by 70%.	Used a newly generated soil bulk density map to estimate peatland N_2O emissions and simulate the effects of rewetting.
Wilson et al. (2016)	Peatland (blanket bog) rewetting	Bellacorick, County Mayo, north-west coast of Ireland	Local (a former blanket bog)	Nearly a decade after rewetting, the GHG balance had become less warming in comparison with the drained site but still indicated a net source of carbon. Rewetting reduced CO_2 emissions in unvegetated areas by approximately 50%.	GHG flux measurements were made over 5 years at the rewetted site, and 2-years at an adjacent drained area. Rewetting followed cessation peat extraction in 1997.

Source	Restoration measure	Location	Scale	Carbon storage & GHG flux benefit	Supporting evidence
Wilson et al. (2022)	Rewetting of a raised bog through drain blocking	Moyarwood, County Galway, Ireland	Local (site covers approximately 230 ha)	The drained area was an annual net CO_2 source before restoration and shifted toward reduced emissions after rewetting, though CH_4 fluxes increased. Rewetting of peatland established optimal conditions for carbon sequestration.	GHG flux measurements were made from 2013 to 2018.
Renou-Wilson et al. (2019)	Rewetting of former raised bogs by drain blocking	Blackwater, County Offaly, Irish Midlands, Ireland	Local (two former raised bogs)	The drained areas of both sites were annual CO_2 and CH_4 sources. Rewetting reduced CO_2 losses but increased CH_4 emissions. Rewetting represents a significant saving in terms of avoided emissions (and thereby has a direct climate benefit).	GHG were monitored at both sites at fortnightly intervals or monthly intervals over several years.
Schwerk et al. (2025)	Peatland restoration by rewetting that raised water levels.	Kampinos wetland, central Poland, and Komppasuo Bog, southern Finland	Individual wetlands	Rewetting resulted in a shallower annual average water table, increasing CH_4 emissions, but this was outweighed by the reduction in CO_2 emissions.	Synthesis report, describing case studies with GHG flux measurements in rewetted sites.
North America					
Armstrong et al. (2022)	Restoration by rewetting of a previously drained peatland	Clayton Blocks Pocosin Restoration Project, Pocosin Lakes National Wildlife Refuge, North	Individual wetland (536 ha; two control drained sites, three rewetted sites)	Despite increases in CH_4 and N_2O after raising the water table, the reduction in CO_2 emissions meant rewetted sites had lower net GHG fluxes than drained controls.	GHG fluxes were monitored at drained and rewetted sites for 7 months before and 7 months after restoration.

Source	Restoration measure	Location	Scale	Carbon storage & GHG flux benefit	Supporting evidence
		Carolina, USA			
Richardson et al. (2023)	Wetland rewetting by raising ground water table to 30 cm, >30 cm and <20 cm below the ground surface.	Pocosin Lakes National Wildlife Refuge, Albemarle-Pamlico Peninsula, North Carolina, USA	Individual wetland (restored, drained, reference sites; plus two adjacent eddy-flux towers)	CO_2 dominated GHG fluxes (99% of total). Keeping the water table 20–30 cm below the surface reduced carbon losses by up to 90%.	Nearly 20 years of data showed soil GHG losses: reference 11.3 Mg C ha^{-1} yr^{-1}, drained 6.8 Mg C ha^{-1} yr^{-1}, restored 5.2 Mg C ha^{-1} yr^{-1}. Drained sites exported 15% more TOC.
Pfeifer-Meister et al. (2018)	Seasonal wetland restoration using herbicide, tilling, thermal and solarization	Coyote Prairie, near Eugene, Oregon, USA	Field experiment (4.5 ha, 50 restoration plots, 5 agricultural plots; plus laboratory experiment with soils from a remnant wetland)	Restoration had no effect on carbon sequestration or GHG emissions. CH_4 and N_2O fluxes were zero, and denitrification was nutrient-limited.	One-year field and lab experiments. Soils had high cation exchange capacity and had received nutrient additions.
McNicol et al. (2017)	Conversion of grassland pasture to wetland in 2010	Mayberry wetland, Sherman Island, Sacramento–San Joaquin Delta,	Individual wetland (121 ha)	CO_2 uptake did not offset CH_4 release, resulting in net radiative warming.	One-year monitoring (2014–2015) showed open-water fluxes: 915 g C–CO_2 m^{-2} yr^{-1}, 2.9 g C–CH_4 m^{-2} yr^{-1}, 62 mg N–N_2O m^{-2} yr^{-1}. Radiative forcing was higher in open-water zones (3.5 kg CO_2-eq m^{-2} yr^{-1}) than vegetated zones (1.4 kg CO_2-eq m^{-2} yr^{-1}).

Source	Restoration measure	Location	Scale	Carbon storage & GHG flux benefit	Supporting evidence
		California, USA			
Arias-Ortiz et al. (2021)	Wetland restoration of grassland in 2010 and corn field in 1997	Mayberry wetland and West Pond marsh, Sacramento–San Joaquin Delta, California, USA	Individual wetlands (121 ha and 3 ha)	Wetlands efficiently buried carbon, but GHG emissions offset CO_2 burial for up to 80 years.	Restoration caused early climate warming due to elevated CH_4 emissions, lasting 2.1 ± 2.0 to 8 ± 4 decades.
Delwiche et al. (2025)	Rewetting of pasture converted to wetland in 2010 by regulating hydrology	Mayberry wetland, Sherman Island, Sacramento–San Joaquin Delta, California, USA	Individual wetland (121 ha)	CH_4 peaked post-rewetting in 2013, then declined sharply, likely due to vegetation-driven oxidation. Seasonal patterns were linked to water table and conductivity.	Three years after rewetting, CH_4 emissions decreased by 4.7 g C m^{-2} yr^{-1} annually until 2024, when emissions rose again.
Hemes et al. (2019)	Wetland rewetting across drained agricultural land and reference sites	Sacramento–San Joaquin Delta, California, USA	Regional (1400 km^2 pre-drainage)	Restored wetlands sequestered carbon effectively, with CO_2 uptake exceeding CH_4 emissions. Restored wetlands do not begin to accrue GHG benefits until nearly 50 years, and become net carbon sinks from the atmosphere after 100 years.	Synthesis of 36 site-years of data showed restored wetlands may take 80 ± 49 years to achieve net climate cooling relative to drained land.
Ma et al. (2024)	Wetland restoration, sorted into three wetland state scenarios (intact, drained,	Inland wetlands in the temperate region of	Continental	Intact wetlands act as CO_2 sinks, degraded wetlands as sources. Restoration of wetlands has immediate climate benefits, with net cooling expected 110 years after restoration.	Modelled regional carbon budgets over 500 years using field data to compare intact, degraded, and restored wetlands.

Source	Restoration measure	Location	Scale	Carbon storage & GHG flux benefit	Supporting evidence
	and drained and then restored).	North America			
Tangen & Bansal (2020)	Wetland restoration, sorted into restored, natural, and drained wetlands	Prairie Pothole Region, USA (Minnesota, North Dakota, South Dakota, Montana)	Regional (549 wetlands across ~160,000 km²)	Restored wetlands require 20–64 years to regain SOC stocks comparable to natural wetlands.	Wetland SOC sequestration rates ranged from 0.35 to 1.10 Mg C ha^{-1} yr^{-1}, varying by landscape position and depth. SOC storage was 66 Mg C ha^{-1} in inner catchments, decreasing to 43 Mg C ha^{-1} toward uplands.
Hinshaw & Wohl (2023)	Stream–floodplain corridor restoration involving large wood additions and reconfigured channel–floodplain connectivity	Nine sites in the western USA (six in Oregon, two in Colorado, one in Washington)	Reach scale (nine river reaches)	Degraded floodplains had the lowest SOC stocks, while restored floodplains had stocks similar to degraded condition floodplains. Quantifying the effects of restoration on floodplain carbon stocks was uncertain.	Degraded floodplains contained 161–894 Mg C ha^{-1}, reference sites 391–904 Mg C ha^{-1}, and restored treatment sites 203–1028 Mg C ha^{-1}, with statistically significant differences between categories.
Strack & Zuback (2013)	Rewetting and revegetation of cutover peatland	Bois-des-Bel peatland, near Rivière-du-Loup, Québec, Canada	Peatland site (7.5 ha restored; compared to undisturbed and unrestored cutover areas)	Restored site achieved GHG balance similar to natural peatland. The unrestored cutover site remained a carbon source.	Restoration began 1999. CO_2 and CH_4 fluxes were measured over 2010. Due to dry conditions, all sites acted as net carbon sources.

Appendix F – Food security benefits from freshwater ecosystem restoration

Source	Restoration measure	Location	Scale	Food security benefit	Supporting evidence
Africa					
Jamu et al. (2023)	No-take fish sanctuaries with co-management	Malawi (Rivers/lakes)	Local/Region	**Rebuilds fish stocks and increases fisher incomes** (F10) - higher biodiversity and sanctuary productivity; potential spillover.	Observed species richness +24%; diversity indices increased; multi-site monitoring.
Morrison et al., (2012); Morrison et al. (2013); Morrison (2013)	Papyrus wetland restoration & sustainable harvest; biomass briquettes (fibre/energy)	Lake Naivasha, Nakuru County, Kenya	Local (wetland margins)	**Delivers quantified food provisioning** (F12) – Restored papyrus provides fibre/fuel, supporting household energy budgets and livelihoods (indirectly food security)	WTP (willingness to pay) ≈ USD 0.21 per 10-briquette cuboid; ~48.3 briquettes m⁻² (~483,000 ha⁻¹); 17.7 km² margin could supply ~765 million briquettes yr⁻¹ (~284k people); value ≈ USD 6,546 ha⁻¹
Asia					
Baird & Flaherty (2005)	Fish Conservation Zones (no-take pools/reaches)	Southern Laos (Mekong tributaries)	Local (river reaches/ pools)	**Rebuilds fish stocks and increases fisher incomes** (F10) – increased abundance and catchability near reserves; spillover to adjacent reaches.	LEK (local ecological knowledge) surveys across villages; consistent reports of increased catch sizes; tonnage not reported.
Fiorella et al. (2019)	Network of 40 Community Fish Refuges (CFRs); hydrological connectivity and governance	Tonle Sap Basin, Cambodia	Region/Local	**Rebuilds fish stocks and increases fisher incomes** (F10) – Higher fish biomass retention and species richness with better-connected CFRs.	Longitudinal sampling 2012–2015; regression links connectivity/governance to biomass/richness.
Mohammed et al. (2025)	Sanctuaries, seasonal bans, gear rules, and co-management (ECOFISH-BD)	Meghna River Basin, Bangladesh	Region	**Rebuilds fish stocks and increases fisher incomes** (F10) – Stock recovery; increased hilsa catch volumes; higher fisher incomes and assets.	Difference-in-difference: income +86.19%; assets +63.99%; ROI (return on investment) 32.8%.
Phala et al. (2019)	CFR: refuge deepening, inlet/outlet channels, enforcement	Srey Snam, Siem Reap, Cambodia	Local (wetland/rice-field system)	**Delivers quantified food provisioning** (F12) – Improved availability of food fish; strengthened community management.	Household survey & management assessment; increased catch reported; biomass not quantified in paper.

Source	Restoration measure	Location	Scale	Food security benefit	Supporting evidence
Coates (2023)	Wetland rehabilitation & co-management (MACH): fish sanctuaries (109 ha), native fish reintroductions (0.77M), dry-season refuges, seasonal closures, endowments	Hail Haor (incl. Baikka Beel), Sylhet Division, Bangladesh	Region (wetland complex)	**Rebuilds fish stocks and increases fisher incomes** (F10)– Higher fish catches and consumption; increased wetland economic value; alternative incomes for poorer households	Catch +88% vs 1999 baseline (171→322 kg/ha by 2005/06); fish consumption +45% (farmers & landless); haor value +24% from fish catch; BCR (Benefit/Cost Ratio) ≈ 4.7; IRR (Internal Rate of Return) ≈ 56%
Coates (2023)	Community cooperative management; weed & sediment removal; catchment tree planting; initial stocking; closed seasons/sanctuaries	Lake Rupa, Kaski District, Nepal	Local (lake)	**Rebuilds fish stocks and increases fisher incomes** (F10) – Fish production and livelihoods increased; reduced dependence on stocking; employment for cooperative members	Fish production 18.5 t (2004) → ~70 t (2010/11); value ≈ USD 90,000; ~80% cooperative members employed; stocking need –60%
Nguyen et al. (2015); IUCN (2021)	Restoring/retaining seasonal flood functions via floating rice–based systems and diversified flood-based agriculture (low dikes, rice–vegetable/cattle rotations)	Upper Vietnamese Mekong Delta (An Giang, Đồng Tháp)	Region/Local (floodplain farms)	**Restores migratory fish runs** (F11) & **delivers quantified food provisioning** (F12) – Higher farm profitability and diversified production from flood-based systems compared to intensive mono-rice under high dikes	Household survey & focus group discussion cost–benefit: net benefit VND 24.8 million/1,000 m² for floating rice–leeks; VND 18.5 million/1,000 m² for floating rice–sweet corn–baby corn & cattle; vs. VND 1.3–4.8 million/1,000 m² for two- or three-crop intensive rice; conversion to two maize crops achieved ~VND 21 million/1,000 m²
Europe					
Pijlman et al. (2019)	Paludiculture (Typha) under wetland hydrology	Netherlands	Local	**Delivers quantified food/fibre/energy provisioning** (F12) – Feed/fibre biomass from restored wetlands.	Field trials & feed evaluation; yields/context reported in paludiculture literature.
WWF (2010); Hein et al. (2016)	Dyke breaches & floodplain reconnection of former polders/fish farms	Babina & Cernovca, Danube Delta, Romania	Local/Region (3,600 ha)	**Restores migratory fish runs** (F11) & **delivers quantified food/fibre/energy provisioning** (F12) – Restored fish breeding/nursery habitats; community income from fish/reed/services.	~US$140k/yr local benefits; 3,600 ha reconnected; qualitative fish spawning/nursery evidence.

Source	Restoration measure	Location	Scale	Food security benefit	Supporting evidence
de Jong et al. (2021)	Rewetting peat & cultivating Typha (paludiculture)	Netherlands	Local/Region	**Delivers quantified food provisioning** (F12) – Biomass (fiber/fodder) production while restoring peatland hydrology.	Feasibility/LCA (Life Cycle Assessment); literature yields often 10–30 t DM/ha·yr; site-specific.
North America					
Atlantic Salmon Federation (2024)	Post-restoration monitoring (fish lift counts)	Milford Fishway, Penobscot, Maine, USA	Site/river reach	**Delivers quantified food provisioning** (F12) – Very large river herring runs supporting fisheries.	2024: 5,476,107 river herring; 10,787 shad (provisional).
Maine Department of Marine Resources (2025)	State commercial landings (context)	Maine, USA	State	**Delivers quantified food provisioning** (F12) – Sustained alewife supply following connectivity restoration statewide.	Alewife landings: 3.30 M lb (2022), 3.21 M lb (2023), 2.51 M lb (2024 prelim.). *1 M lb = 453.6 metric tonnes.
Whittum et al. (2023)	Dam removals + fish passage (Penobscot)	Penobscot River, Maine, USA	River basin	**Restores migratory fish runs** (F11)Reopened access for diadromous fish underpinning bait/food supply.	Assemblage shift post-removal; see direct counts and landings entries below for quantities.
Oceania					
Delaney et al. (2009); Bayliss & Ligtermoet (2014); McMaster et al. (2014); Kranney (2019)	Para grass (*Urochloa mutica*) control and restoration of sedgeland wetlands (*Eleocharis dulcis*) through burning and targeted glyphosate spraying with the aim to improve numbers of magpie goose (*Anseranas semipalmata*), traditionally an important food source and culturally significant for Aboriginal peoples of northern Australia	Kakadu floodplains, Northern Territory, Australia	Region/basin (para grass infestations mapped across 181 km² with 48 km² core areas)	**Restores migratory fish runs** (F11) & **delivers quantified food provisioning** (F12) – Recovery of sedgeland food plants and magpie goose habitat, with magpie goose numbers in one restored wetland increasing from ~50 in 2018 to ~1,800 after interventions; although, it is known that stream flow drives the spatial and temporal dynamics of magpie geese through direct influence on floodplain-vegetation	Information includes data on para grass invasion impacts, importance of sedgelands for Indigenous bush foods, costed control trials (burning plus glyphosate) and aerial monitoring of infestations; drone-assisted mapping and Indigenous-led control resulted in rapid recovery of open water and magpie goose numbers.

Source	Restoration measure	Location	Scale	Food security benefit	Supporting evidence
White et al. (2022); Baker et al. (2014); Jones & Hamilton (2014); Abell et al., 2022); Collier et al. (2017); Pingram et al. (2021)	Culvert remediation, barrier removal for fish passage improvements, riparian planting and weed control, and creation of spawning habitat for īnanga—Common galaxias (*Galaxias maculatus*) also known as "whitebait", an important traditional food on the Waikato River, especially for Māori.	Waikato River and tributaries, New Zealand	Catchment	**Restores migratory fish runs** (F11) – Improved īnanga migration and spawning conditions expected to support whitebait fishery; site-specific factors can still result in restricted passage for weak swimming fish such as inanga	Hydrodynamic modelling identified relationships between īnanga habitat and tidal/hydrological variability. Electrofishing surveys were conducted at remediated barriers. Inanga historically provided cash income and now commands high prices as a luxury food.
South America					
Campos-Silva & Peres (2016)	Protected/community-managed lakes (access control; surveillance; managed harvest)	Juruá River floodplain, Brazil	Region/Local (83 lakes)	**Rebuilds fish stocks and increases fisher incomes** (F10) & **Restores migratory fish runs** (F11) & **Delivers quantified food provisioning** (F12) – Arapaima stocks and revenues higher in protected lakes; improved household income.	Mean arapaima per lake: 304.8 vs. 9.2 (protected vs. open-access); ~US$10,600/community/yr; 8-year monitoring.
Petersen et al. (2016)	Community-based management (quotas, closed seasons, monitoring)	Purus River floodplains, Brazil	Region/Local	**Restores migratory fish runs** (F11) & **Delivers quantified food provisioning** (F12) – Arapaima recovery enabling sustainable harvests.	Before-after/control increases in arapaima densities; tonnage not reported.

Appendix G – Cultural and recreational benefits from freshwater ecosystem restoration

Source	Restoration measure	Location	Scale	Cultural and recreational benefit	Additional information
Global					
Basak et al. (2021)	River restoration (social outcomes review)	Global (focus on developed countries)	Various	**Increased outdoor recreation and tourism** (F13). **Strengthened cultural and spiritual connections** (F14) **Improved aesthetic quality and community well-being** (F15) – Improved community well-being, including recreation, cultural connection to rivers, and mental health benefits.	Case studies noted increased public use of restored rivers (fishing, kayaking, nature walks) and greater community engagement in stewardship.
Kaiser et al. (2020)	River restoration (various methods)	Predominantly N. America & Europe (review of 850 studies	Various	**Increased outdoor recreation and tourism** (F13). **Improved aesthetic quality and community well-being** (F15) – Of 88 studies quantitatively assessing services, a majority showed enhanced recreational and aesthetic benefits after restoration.	Systematic review of river restorations found clear positive impacts on numerous services.
Asia					
Koh et al. (2022)	Converted a 2.7 km concrete drainage canal into a naturalized meandering river with wetlands, floodplains, and park amenities	Singapore	Urban park (63 ha)	**Increased outdoor recreation and tourism** (F13). **Improved aesthetic quality and community well-being** (F15). Park usage surged – annual visitation doubled from ~3 million to 6 million after restoration.	Surveys and online reviews show positive public perceptions of the new river landscape (e.g. ~94% of sentiments in reviews were positive).
Lee et al. (2016), Kang et al. (2015)	Daylighting and naturalization of a buried, concreted urban stream	Seoul, South Korea	Urban river (~5.8 km)	**Increased outdoor recreation and tourism** (F13). **Improved aesthetic quality and community well-being** (F15) – annual economic value of the restoration project estimated at US $170 million primarily based on 'consumer welfare' due to the value of environmental quality improvement.	Cost of project ultimately exceeded project benefits (final benefit-cost ratio of 0.75 cf. 1.89 during assessment phase) due to higher than anticipated construction costs
Europe					
Deffner & Hasse (2018)	Review of perceptions of the benefits of restored rivers based on surveys and interviews.	Germany	Users at 3 restored rivers, plus	**Increased outdoor recreation and tourism** (F13). **Improved aesthetic quality and community well-being** (F15)	Restored river sections are perceived positively by > 80% of the respondents. >90% consider both the ecosystem and residents profit highly

Source	Restoration measure	Location	Scale	Cultural and recreational benefit	Additional information
			broader phone survey		from the restoration measure. 70% regard further restoration projects as useful (6% not useful).
EEA (2016)	Widened and re-profiled an urban river stretch removed concrete embankments, and restored floodplains	Isar River, Munich, Germany	Urban river	**Increased outdoor recreation and tourism** (F13). **Improved aesthetic quality and community well-being** (F15) – achieved bathing water quality, allowing swimming in the Isar for the first time in decades.	
North America					
Isely et al. (2018)	Wetland creation/shoreline softening; removal of fill and hardened banks.	Muskegon Lake, Michigan, USA	~10.9 ha wetlands, 3 km shoreline	**Increased outdoor recreation and tourism** (F13) & (F14) **Improved aesthetic quality and community well-being** (F15) – Increased decreation value ≈ US$38.1 m NPV (20 yrs) via increased trips; total local economic benefits ≈ US$60 m on a US$10 m project; property value gains ≈ US$7.9 m and ~485,000 extra annual visits post-restoration.	Restoration following designation as a Great Lakes Area of Concern
Leisher et al. (2022)	Removal of two large dams to restore free-flowing river	Penobscot River, Maine, USA	Regional river scale	**Increased outdoor recreation and tourism** (F13). **Strengthened cultural and spiritual connections** (F14) **Improved aesthetic quality and community well-being** (F15) - five years after dam removal, perceptions of water quality, swimming, paddling, fishing, and wildlife viewing increased, and the percentage of people saying the river was "part of their family's life" increased.	
Ogston et al. (2014)	Floodplain reconnection and off-channel habitat creation	Chilliwack River, BC Canada	Catchment scale	**Increased outdoor recreation and tourism** (F13). **Strengthened cultural and spiritual connections** (F14) – Wild coho salmon smolt production had increased by an estimated 27–34%, a species of cultural importance for First Nations.	~157,000 m² of new floodplain ponds and channels built between 1996–2000.
Oceania					
Bell et al. (2020)	Restoration of natural hydrology by reconnecting Lake Condah and re-wetting	Budj Bim Cultural Landscape, southwestern	Regional scale	**Increased outdoor recreation and tourism** (F13). **Strengthened cultural and spiritual connections** (F14) – Restoration allowed the revival of traditional Gunditjmara eel farming practices and significantly	

Source	Restoration measure	Location	Scale	Cultural and recreational benefit	Additional information
	wetlands to restore traditional eel aquaculture and cultural practices	Victoria, Australia		enhanced cultural connections to the landscape. World Heritage recognition in 2019 boosted eco-cultural tourism, which has in turn brought economic benefits.	
Lloyd & Finlayson (2020)	Decommissioned a 1970s irrigation dam (Lake Mokoan) to restore 8,750 ha of wetlands, lakes and woodlands	Victoria, Australia	Large wetland reserve in northeast (rural/regional scale)	**Increased outdoor recreation and tourism** (F13). **Strengthened cultural and spiritual connections** (F14) **Improved aesthetic quality and community well-being** (F15) - Near doubling of visitor numbers from 2016/17 to 2018/19 for walking, cycling birdwatching, canoeing. Large increase in school visits. Recognition of indigenous cultural heritage sites. Visitor hub and cafe host regular events.	

Appendix H – Biodiversity and ecosystem services benefits from freshwater ecosystem restoration

Source	Restoration measure	Location	Scale of restoration	Biodiversity/supporting benefit	Supporting evidence
Africa					
UNESCO WHC (2010); Hamdi et al. (2012)	Hydrological management and sluice operation to restore seasonal inundation and reduce salinity	Ichkeul National Park, Tunisia	Region/basin	**Hydrology driving multi-taxa recovery** (F16) & **River/floodplain reconnection driving ecosystem-wide gains** (F17) – Recovery of flood-pulse wetland function and large wintering waterbird aggregations	National/WH monitoring reports indicate post-management sustained wintering numbers on the order of 100,000 waterbirds in typical years and >300,000 in some years; historical analyses show declines during high-salinity years and improvement with restored freshwater inputs and vegetation.
Bellingan et al. (2019); Weyl et al. (2016); Weyl et al. (2014)	Eradication of alien smallmouth bass using rotenone; recovery of native fish and macroinvertebrates	Rondegat River, Western Cape, South Africa	Local (river reach)	Rapid recovery of native macroinvertebrates and re-establishment of endemic fishes after invasive predator removal	BACI design with 2 years pre- and 2 years post-treatment: macroinvertebrate assemblages showed no lasting negative effects and recovered rapidly; native fish densities increased within 1 year; alien bass eliminated from the treated 4 km reach (2012–2015 monitoring).
Loth (2004); Scholte et al. (2006)	Partial reflooding by breaching embankments and reopening distributaries to restore seasonal flood pulse	Waza-Logone floodplain, Extreme North Region, Cameroon	Region/basin	**Hydrology driving multi-taxa recovery** (F16) & **River/floodplain reconnection driving ecosystem-wide gains** (F17) – Large increases in waterbird abundance/diversity following restoration; hydrological reconnection increased typical annual flood extent	Multi-year aerial/ground counts showed key species increases of +135% to +744% after reflooding; species exceeding Ramsar 1% criterion rose (e.g., 6 to 12). Flood extent increased by ~1,000–1,500 km² in typical years post-intervention.

Source	Restoration measure	Location	Scale of restoration	Biodiversity/supporting benefit	Supporting evidence
Asia					
Baragangina RMO (2017); Thompson (2008); Winrock International (2007); MACH (2003); CNRS (2023)	Permanent community fish sanctuary; canal excavation; habitat restoration and protection; seasonal fishing bans during spawning	Baikka Beel sanctuary, Hail Haor, Moulvibazar, Bangladesh	Local (100 ha wetland)	Higher wintering waterbird use and spillover benefits to fisheries in the wider haor	Fish catches in the wider Hail Haor doubled from ~170–200 kg/ha (1999–2000) to ~390–400 kg/ha by 2004–2010; wintering waterbirds rose from 300 of 16 spp. in Jan–2004 to 7,200 of 35 spp. in Jan–2007; >12,000 waterbirds during winter 2006—2007.
He et al. (2021); Zhang et al. (2021)	Wetland restoration via dyke works and water-level management to maintain winter water habitats	East Dongting Lake, Hunan, China	Local (protected wetland units)	**River/floodplain reconnection driving ecosystem-wide gains** (F17) & **Wetland restoration enables recovery of specialist communities** (F19) – Higher wintering waterbird species richness, density and diversity in restored units relative to unrestored controls across multiple guilds	Annual surveys (2012/13–2019/20) comparing restored vs. unrestored units showed consistently higher richness and density; BACI-style comparisons linked gains to increased open-water and diverse depth habitats created by managed water levels.
Ding et al. (2019)	Low-head dam removal to restore longitudinal connectivity	Jidu River (tributary of the Lancang/Mekong), Yunnan, China	Local (river reach)	**Barrier removal restores fish and aquatic communities** (F17) – Upstream fish species richness and abundance increased; assemblage more similar to free-flowing control	Before-after-control-impact design: significant increases in richness and abundance upstream of the former barrier; temporal homogenisation of communities toward reference conditions.
Richardson & Hussain (2006)	Reflooding of drained marshes via levee breaches and flow restoration	Mesopotamian Marshes, southern Iraq	Region/basin	**Hydrology driving multi-taxa recovery** (F16) & **River/floodplain reconnection driving ecosystem-wide gains** (F17) – Rapid recovery of marsh vegetation and fauna as inundation expanded	Field surveys and remote sensing (2005–2008) recorded broad species return and large seasonal aggregations as ~39% of former marsh extent re-inundated by 2005.

Source	Restoration measure	Location	Scale of restoration	Biodiversity/supporting benefit	Supporting evidence
Europe					
Ioana-Toroimac et al. (2024); Mansourian et al. (2019)	Levee breaches; side-arm reconnections; floodplain forest restoration over ~20 years	Lower Danube, Romania/Bulgaria	Region/basin	**Hydrology driving multi-taxa recovery** (F16) & **River/floodplain reconnection driving ecosystem-wide gains** (F17) – Hydrological reconnection achieved at many sites; increases in native floodplain forest extent/condition	Hydrological indicators confirm reconnection effectiveness; programme-scale reporting documents restored forest extent and improved habitat condition.
Bregnballe et al. (2009, 2014)	Re-meandering; dyke removal; re-wetting of ~22 km² floodplain; adaptive water-level management	Skjern River Valley, Jutland, Denmark	Region/basin	**Hydrology driving multi-taxa recovery** (F16) & **River/floodplain reconnection driving ecosystem-wide gains** (F17) – Breeding and staging waterbirds increased; 29 breeding species recorded, incl. 10 of European conservation concern	Standardised breeding and staging counts (2002–2005) showed sustained increases across dabbling ducks, swans and geese as habitat mosaics and managed water levels were restored.
Lamers et al. (2014)	Rewetting; phosphorus-load reduction; restoring base-rich groundwater inputs	Rich fens across Europe & North America	Multiple local projects (review)	**Hydrology driving multi-taxa recovery** (F16) – Recovery of specialist fen plant communities and habitat quality	Evidence-based guidance synthesised from multi-year monitoring shows return of characteristic fen species under restored hydrology/nutrient regimes.
Kail et al. (2015)	Physical habitat restoration (e.g., widening, reconnection, meandering)	European rivers (multiple)	Multiple local projects	**River/floodplain reconnection driving ecosystem-wide gains** (F17) – Improvement in fish, macroinvertebrates and aquatic macrophytes post-restoration	Meta-analysis shows biotic indices improve where channel morphology and habitat complexity are re-naturalised.
North America					
Duda et al. (2021); Brenkman et al. (2019)	Removal of Elwha & Glines Canyon dams; longitudinal connectivity restored	Elwha River, Washington, USA	Basin	**Barrier removal restores fish and aquatic communities** (F17) – Rapid recolonisation by migratory fish; redistribution of	Within ~2.5 years: 8 anadromous species upstream of former barriers; ~5 years: 8/9 migratory species passed former dam site;

Source	Restoration measure	Location	Scale of restoration	Biodiversity/supporting benefit	Supporting evidence
				salmonids as sediment regime stabilised	snorkel/telemetry/eDNA confirm increased densities in mid-river reaches.
Koebel & Bousquin (2014a; 2014b); Cheek et al. (2014); Spencer & Bousquin (2014); Bousquin & Colee (2014); Anderson (2014); USACE (n.d.); SFWMD (n.d.)	Re-meandering; removal of control structures; floodplain reconnection and seasonal re-inundation	Kissimmee River, Florida, USA	Region/basin	**Hydrology driving multi-taxa recovery** (F16) & **River/floodplain reconnection driving ecosystem-wide gains** (F17) – Multi-taxa recovery: floodplain vegetation expanded; littoral plant community shifted to emergents; wading-bird densities increased; fish assemblage shifted toward sport fishes; water quality improved	Vegetation mapping showed wetland extent >2× within 2 years of Phase I and near pre-channelization by 2008; littoral stands narrowed with emergent dominance; organic bed layer ↓ ~71% with 72 point bars re-formed by 2009; wading-bird density ≥30.6 birds km^{-2} target met/exceeded; bass/sunfishes increased 38%→68% of assemblage; dissolved oxygen up to six-fold higher (long-term programme).
Abbott (2023)	Small-dam removal; channel/flow restoration at multiple sites	Massachusetts, USA (multiple rivers)	Multiple local sites	**Barrier removal restores fish and aquatic communities** (F17) – Water quality improved and biota shifted toward reference assemblages	Before-after and space-for-time designs showed DO ↑ within ~1 year; temperatures cooled at former impoundments; sensitive macroinvertebrates and fish increased within ~3–5 years.
Whittum et al. (2023)	Mainstem dam removals and basin-scale connectivity actions	Penobscot River, Maine, USA	Basin	**Barrier removal restores fish and aquatic communities** (F17) – Fish assemblages shifted toward riverine/diadromous guilds following reconnection	Comparative pre/post analyses documented guild shifts consistent with improved longitudinal connectivity.
Oceania					
Watts et al. (2022)	Managed environmental flow deliveries (pulsed watering)	Edward/Kolety-Wakool System, NSW, Australia	Large floodplain site	**Hydrology driving multi-taxa recovery** (F16) – Improved recruitment signals for native fish; positive responses of frogs and riparian/aquatic vegetation	Long-term monitoring shows higher larval production and recruitment indices in watered years; multi-taxa responses across seasons.
Brandis et al. (2023); Spencer et al. (2023)	Managed environmental flows to support colony breeding and foraging habitat	Gwydir Wetlands, New South Wales, Australia	Large floodplain site	**Hydrology driving multi-taxa recovery** (F16) – Large multi-rookery breeding events and high rookery-scale	2022–23 monitoring recorded ~55,000 total nests across the event, with rookery-specific drone counts (e.g., ~4,000 straw-necked ibis nests at Goddard's Lease) and managed low

Source	Restoration measure	Location	Scale of restoration	Biodiversity/supporting benefit	Supporting evidence
				productivity under managed flows	flows (~8,000 ML delivered) maintaining inundation to fledging.
EcoFutures Consulting Australia (2024); GHD (2023); MDBA (2024)	Managed environmental water to reconnect floodplain lakes and sustain inundation through breeding	Hattah Lakes Icon Site, Victoria, Australia	Large floodplain site	**Hydrology driving multi-taxa recovery** (F16) & **River/floodplain reconnection driving ecosystem-wide gains** (F17) – Establishment and completion of colonial waterbird breeding events supported by managed inundation	Icon-site monitoring and intervention reports (2022–23) document rookery establishment, persistence and successful fledging under targeted watering actions.
Brandis et al. (2023)	Managed environmental flows supporting large colonial waterbird breeding events	Macquarie Marshes, New South Wales, Australia	Large floodplain site	**Hydrology driving multi-taxa recovery** (F16) – Sustained large-scale ibis/egret/spoonbill breeding across multiple rookeries under managed flows	CEWO/UNSW monitoring: >116,000 nests (2021–22) across four colonies; >107,000 nests (2022–23) across three colonies; rookery-scale reproductive success ~63–78% documented via repeat drone surveys.
Duggan et al. (2012); Macdonald & Robertson (2017)	Integrated wetland management (weed/pest control, water-level management, habitat works) within a national programme	Whangamarino Wetland, Waikato, New Zealand	Large floodplain site	**Wetland restoration enables recovery of specialist communities** (F19) – Sustained occupancy of threatened wetland birds (e.g., Australasian bittern) with targeted management	Multi-year outcomes report (2007–2011) documents management actions linked to acoustic call-count indices; quantitative pre/post increases solely attributable to restoration are still being developed—include as indicative NZ case.
South America					
Brück et al. (2023); Joslin (2021); Thompson et al. (2021)	Peatland/páramo rewetting (canal blocks), grazing exclusion/stock removal, community agreements, landscape protection	Quito watershed, Ecuador	Region/basin (Antisana Water Conservation Area)	**Hydrology driving multi-taxa recovery** (F16) & W**etland restoration enables recovery of specialist communities** (F19) Return/use by condor, puma, deer; vegetation recovery; stabilised peatland water table	~8,500 ha protected; >4,400 ha in conservation agreements; monitoring initiated 2021 (camera traps); specific peatland water-table stabilisation at Pugllohuma, and erosion reduction.

For a future where people and nature thrive | wwf.org.uk