Federal Agency for Nature Conservation

Riverine and coastal wetlands in Europe for biodiversity and climate

State of knowledge, challenges and opportunities

June 2023

DISCUSSION PAPER

Imprint

Published by:

Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN)
Konstantinstr. 110, 53179 Bonn, Germany

Phone: +49 228 8491-0
E-mail: info@bfn.de

Internet: www.bfn.de

Tax ID number: DE 122268582

This publication was commissioned by the Federal Agency for Nature Conservation as part of Project 'BioClim-Wetlands' with funds from the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) (FKZ: 3521830200).

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DOI 10.19217/hgr233en

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Summary

This publication provides a background document and knowledge base for the European Conference **"Riverine and coastal wetlands for biodiversity and climate – Linking science, policy and practice"**, hosted by the Federal Agency for Nature Conservation (BfN) and the European Network of Heads of Nature Conservation Agencies (ENCA) in September 26th-28th, 2023, in Bonn, Germany. It presents key findings of a preparatory European expert workshop on the conference topic, implemented on November 29th-30th, 2022.

- Riverine and coastal wetlands are vital ecosystems for nature and people, while playing a crucial role in mitigating and adapting to climate change. They are considered hotspots for biodiversity and provide important ecosystem services to people, such as climate and water regulation, carbon sequestration and retention, flood prevention and water filtration, as well as food provision and opportunities for recreation.
- Inland and coastal wetlands have, however, drastically declined by about 35% between 1970 and 2015 (Ramsar Convention on Wetlands, 2018). This has serious consequences for both people and nature, accelerating climate change by releasing greenhouse gases (IPCC, 2022) while limiting opportunities to buffer climate change impacts.
- Climate change has significant impacts on riverine and coastal wetland ecosystems and their biodiversity. Among these are long-term effects on the landscape, the water balance and groundwater levels through rising sea levels, changing precipitation and resulting discharge patterns, increased temperatures, and shifts in species compositions. These inevitable changes threaten their unique biodiversity and related ecosystems services.
- In many wetlands, irreversible changes in river morphology or soil physicochemical properties due to land use and long-term drainage make it unlikely that a natural state can be achieved from rewetting within a few decades. Thus, the focus must be on protecting remaining wetlands, as well as on adaptive management to improve restoration outcomes.
- Wetland conservation, restoration and sustainable management can play a key role as nature-based solutions for both climate change adaptation and mitigation, e.g., by ensuring flood risk reduction and carbon sequestration.
- Significant progress has already been made in wetland restoration in Europe, but there are still key barriers to overcome. Challenges include conflicting land use priorities, a lack of effective implementation and enforcement of legal frameworks, and a lack of funding. In addition, a lack of standardised monitoring of restoration success prevents accountability to policy goals. Accompanying research is needed to better understand the effectiveness of restoration techniques and to be able to scale up good practices.
- To effectively protect and prepare ecosystems in the face of climate change impacts, it will be necessary to consider a range of approaches, including policy reforms, the use of new land management tools, emerging technologies for planning and monitoring, as well as better stakeholder engagement with social and organisational tools.
- Involving local communities can play a critical role in the co-design of wetland restoration, conservation, and management plans, not only as stakeholders but also through the integration of local knowledge and expertise. Involving people in both decision making and planning, as well as practical restoration, can build social capital and social licence for implementation and enable collective efficacy as a driver for transformative change.

Zusammenfassung

Diese Publikation stellt ein Hintergrunddokument und eine Wissensbasis für die Europäische Fachkonferenz "Riverine and coastal wetlands for biodiversity and climate - Linking science, policy and practice" dar, die vom Bundesamt für Naturschutz (BfN) und dem Europäischen Netzwerk der Leitungen der Naturschutzämter (ENCA) vom 26.-28. September 2023 in Bonn ausgerichtet wird. Es fasst die wichtigsten Ergebnisse eines vorbereitenden europäischen Expert*innenworkshops zum Konferenzthema vom 29.-30. November 2022 zusammen.

- Flussauen und Küstenfeuchtgebiete sind lebenswichtige Ökosysteme für Natur und Mensch, und sowohl für den Klimaschutz als auch für die Klimafolgenanpassung entscheidend. Sie und gelten als Biodiversitäts-Hotspots und stellen unverzichtbare Ökosystemleistungen wie Klimaregulierung, Kohlenstoffbindung, Hochwasserschutz, Wasserfiltration, Nahrungsmittelversorgung und Erholungsmöglichkeiten bereit.
- Binnen- und Küstenfeuchtgebiete sind jedoch drastisch zurückgegangen, zwischen 1970 und 2015 um etwa 35 % (Ramsar Convention on Wetlands, 2018). Dies hat schwerwiegende Folgen für Mensch und Natur, da einerseits durch den Verlust Treibhausgase freigesetzt werden, die zur Beschleunigung des Klimawandels führen (IPCC, 2022), und andererseits Potentialflächen für die Anpassung an Klimawandelfolgen verloren gehen.
- Der Klimawandel wirkt sich erheblich auf Flussauen und Küstenfeuchtgebiete sowie auf ihre biologische Vielfalt aus. Langzeitauswirkungen umfassen Veränderungen in der Landschaft und im (Grund-)Wasserhaushalt, durch den Anstieg des Meeresspiegels und veränderten Niederschlags- und Abflussmustern sowie Artenzusammensetzungen. Diese unvermeidlichen Entwicklungen bedrohen die einzigartige biologische Vielfalt der Feuchtgebietsökosysteme ebenso wie ihre wertvollen Ökosystemleistungen.
- Aufgrund irreversibler Veränderungen der Flussmorphologie oder der physikochemischen Eigenschaften des Bodens infolge von dauerhafter Entwässerung, ist in vielen Feuchtgebieten das Erreichen eines natürlichen Zustands durch Wiedervernässung unwahrscheinlich. Renaturierungsbestrebungen sollten deswegen den Schutz der verbleibenden Feuchtgebiete und angepassten Managementstrategien fokussieren.
- Die Erhaltung, Wiederherstellung und das nachhaltige Management von Feuchtgebieten sind als naturbasierte Lösungen sowohl für den Klimaschutz als auch zur Klimafolgenanpassung entscheidend, z.B. durch Hochwasserrisikominimierung und Kohlenstoffbindung.
- In Europa wurden bei der Renaturierung von Feuchtgebieten bereits beachtliche Erfolge erzielt. Es gilt jedoch noch grundlegende Herausforderungen zu überwinden, darunter konkurrierende Landnutzungsinteressen, mangelhafte Um- und Durchsetzung von Rechtsvorschriften sowie erhebliche Finanzierungslücken. Standardisierte Erfolgskontrollen sowie ausreichende Begleitforschung fehlen, was das Verständnis der Wirksamkeit von Wiederherstellungsmaßnahmen, den Nachweis der Erreichung politischer Ziele, sowie die Identifizierung und Übertragung erfolgreicher Vorgehensweisen für ein adaptives Management erschwert.
- Für den effektiven Schutz und die Klimafolgenanpassung muss eine breite Palette von Ansätzen angewendet werden. Dazu gehören politische Reformen, der Einsatz neuer Landmanagementinstrumente, innovative Technologien für Planung und Kontrolle sowie eine bessere Einbeziehung aller Akteure durch soziale und organisatorische Instrumente.

- Die Einbeziehung der lokalen Bevölkerung kann eine entscheidende Rolle bei der Mitgestaltung von Wiederherstellung, Erhaltung und dem nachhaltigen Management von Feuchtgebieten spielen - als Interessenvertreter*innen, aber auch durch das Einbringen von lokalem Wissen und Erfahrung. Eine breite Beteiligung an Entscheidungsprozessen, Planung und Umsetzung baut soziales Kapital und Akzeptanz auf und fördert kollektives Handeln als eine treibende Kraft für einen transformativen Wandel.

Figure 1: Wetland in the Rhône delta, France. / Feuchtgebiet im Rhône-Delta, Frankreich. (Source: Simone Wulf, BfN)

1 Introduction

Riverine and coastal wetlands are important ecosystems due to their significant role in supporting biodiversity on multiple scales (from genes to populations, species, communities, and ecosystems) and providing essential benefits for human health and well-being. Even though they only cover 7 % of the earth's surface, wetlands harbour most of the world's available freshwater and provide essential habitats for thousands of species of aquatic and terrestrial plants and animals (40 % of all known species; Wetlands International 2020). Wetlands provide vital climate and water regulation services, such as sequestering carbon, enabling floodwater retention, balancing groundwater tables, improving water quality and serving as filters (or sinks) for sediments and pollutants. In addition, they are important areas for food provision and recreation opportunities for people, and they support natural habitats for highly specialised flora and fauna. This remarkable range of ecosystem services makes them among the most valuable compared to other types of ecosystems.

With a changing climate, increased temperatures and changes in precipitation and discharge patterns can lead to more frequent and/or intense droughts and floods. These impacts have long-term effects on the (ground) water balance of the landscape, leading to a loss of species that are dependent on these habitats. Wetland losses are also driven by human activities, including land use changes, urbanisation and agricultural expansion in coastal zones, river deltas and floodplains, as well as the physical alteration of water courses. As a result, wetlands are extremely threatened all over the world, resulting in area losses at a faster rate than any other major ecosystem. Between 1970 and 2015, inland and marine/coastal wetlands both declined by approximately 35 % (Ramsar Convention on Wetlands 2018). Their loss will amplify climate change by releasing large amounts of greenhouse gases (IPCC 2022).

While we are experiencing rapid wetland decline, their significant contributions to human health and well-being, as well as their role for biodiversity conservation, climate change mitigation and adaptation, is increasingly being recognized. To ensure that they continue to deliver vital benefits to people, their ecological functioning must be maintained, which may require action both inside and outside of wetlands (Friberg et al. 2016). Therefore, the conservation, restoration and sustainable management of wetlands must be prioritised, accompanied by monitoring to foster good practice.

The aim of this paper is to present **recent developments in science, practice, and policy** related to the role of **riverine and coastal wetlands[1] in Europe for biodiversity and climate**. The content is based on the outcomes of an expert workshop on this topic, organized virtually on November 29th-30th, 2022, with the participation of 50 experts from 14 European countries. The workshop was jointly organized by the German Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN) and the Interest Group on Climate Change of the European Network of Heads of Nature Conservation Agencies (ENCA), within the framework of a project supported by BfN with funds from the German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMUV) and implemented by the Helmholtz-Centre for Environmental Research (UFZ) and the German Centre for Integrative Biodiversity Research (iDiv).

[1] Peatlands are only addressed as part of floodplains or estuaries, as they are already well-covered in various other publications (e.g. Bonn et al. 2016, Joosten 2015, Humpenöder et al. 2020, Tanneberger et al. 2021, Zak et al. 2022).

2 Links between wetlands, biodiversity and climate change

2.1 Europe's riverine and coastal wetlands - definitions of terms

The Ramsar Convention on Wetlands, the international treaty for the conservation, restoration, and sustainable use of wetlands, defines wetlands in article 1.1 as:

"…areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres." (Ramsar Convention 1971).

Europe has an extensive coastline spanning 66,000 km with numerous lowlands nestled between major mountain ranges such as the Ural, the Alps, and the Pyrenees, with many rivers flowing from there to the sea (Verhoeven 2014). This leads to numerous wetlands of many different types such as wet depressions, floodplains, brackish marshes, and mudflats in the estuaries (Verhoeven 2014). Historically, Europe had fairly extensive wetlands, with large areas of peatlands, especially in the north, and floodplains and estuarine wetlands in the lowlands near the coast (Verhoeven 2014). Annex I of the European Habitats Directive (EU/92/43/EEC 1992) lists 40 wetland habitat types for Europe, defined largely by their plant species composition. They can be broadly classified into: coasts/marine wetlands (e.g., shorelines, coral reefs), deltas/estuaries (e.g., mudflats, salt marshes), rivers and floodplains (including oxbows and river islands), swamps/marshes (e.g., fens, peatlands), lakes/ponds, and man-made wetlands (Silva et al. 2007, Stuip et al. 2002). This work focuses on riverine and coastal wetlands.

Figure 2: Riverine wetlands at the mouth of the Saale River into the Elbe River, Germany. (Source: André Künzelnmann, UFZ)

Box 1: Riverine wetlands / Floodplains

Riverine wetlands are low-lying areas adjacent to rivers that are regularly inundated with water in times of high discharge (Tockner & Stanford 2002). Depending on climatic, geological, and hydrological characteristics, different wetland types such as fens, floodplains and shallow lakes may occur in close proximity. If we focus on floodplains, they can be distinguished from a hydrological perspective into "active floodplains" (intermittently inundated), and "former floodplains" (anthropogenically disconnected from natural flow dynamics e.g., due to dikes). In active floodplains near natural habitat conditions may remain, including typical habitats such as side-channels, wetlands, oxbow lakes or river banks, whereas former floodplains are mostly used for farming and settlements without provision of natural ecosystem functions and services. With a coverage of 7 % of the European continent, floodplains are an essential component of Europe's natural capital, accounting for up to 30 % of the terrestrial Natura 2000 site area (EEA 2020). Improving floodplain status is crucial for achieving good ecological status under the Water Framework Directive (WFD) and for enhancing the diversity of species and habitats in the context of EU Nature Directives (EEA 2016, 2020).

Box 2: Coastal wetlands

Coastal wetlands are defined as areas along coastlines within an elevation gradient, from subtidal depth (light supporting the growth of underwater plants) to the landward edge, which is subject to regular or occasional flooding by tides, including astronomical and wind-driven tides (Wolanski et al. 2009). Parts of these wetlands can also be influenced by groundwater or freshwater discharge causing complex and dynamic hydrology, affecting both nutrient cycling and carbon as well as heterogeneous biodiversity patterns (Wolanski et al. 2009). Coastal wetlands typically include saltwater-influenced tidal marshes, which may be classified as salt or brackish marshes, as well as shallow lagoons, reefs and seagrass beds (Scott et al. 2014). Mangroves are also considered as an important type of coastal wetland, but they are generally found in tropical and subtropical regions and their distribution range does not extend to Europe. Tidal marshes are found throughout Europe's entire coastline, from the Mediterranean and Black Seas in the south to the Arctic Ocean in the north. Coastal wetland ecosystems have suffered severe losses in area and ecological function, and face problems like, for example, deteriorating water quality, the disappearance of intertidal habitats through coastal squeeze and land conversion, and global challenges due to coastal development and climate change (Newton et al. 2020).

Figure 3: Coastal wetland as a habitat for birds, Scotland. (Source: Simone Wulf, BfN)

2.2 Wetlands for biodiversity – values under threat

Due to their transitional position between permanently aquatic and terrestrial habitats, riverine and coastal wetland ecosystems represent zones of above-average intensity of ecological processes and biological diversity. The flood pulses contribute to water, nutrients, and new habitat structures, resulting in high productivity of specialised plant and animal species. Their shallow waters are cradles for aquatic fauna and flora, while during the dry phase, terrestrial species benefit. Hydrological patterns, for instance, set the stage for sequentially alternating species communities (Junk & Wantzen 2004), and plant successions are regularly set back by morphogenic flood events, thereby creating a dynamic mosaic of habitats (Tockner & Stanford, 2002). Wetlands sustain bird, amphibian, invertebrate, and plant species by providing spawning grounds for fish and breeding and feeding areas for many migratory birds (Silva et al. 2007). Especially in coastal wetlands, the unique combination of fresh-water and saltwater creates a special habitat that supports a diverse array of plant and animal species (Barbier et al. 2011).

The important ecological functions of wetlands should make them priority areas for biodiversity conservation, but despite their importance, they are among the most threatened ecosystems in Europe. Generally, this is due to reclamation, embankment, drainage, infrastructure development, the blocking of water inflows, the over-exploitation of groundwater resources, the construction of dams, channelization, riverbed incision, gravel and sand extraction and various other land use changes that convert wetland habitats into land for agriculture, urban or industrial development. Although the practice of drainage has been carried out for centuries, its intensity has increased dramatically over the last 50 years and it is the primary cause for the loss of environmental functions and ecological processes (Silva et al. 2007). Beyond that, a global analysis found that only one-third of the world's major rivers still flow freely (Grill 2019), due to longitudinal fragmentation from dams, for the purpose of navigation or hydropower. Besides the lack of longitudinal connectivity, human-caused alterations such as the flow regulation for navigation, the embankments of rivers, and the building of dikes for floodplain reclamation or flood protection have disrupted the lateral connectivity of European river systems, leading to a loss of 90 % of active floodplains (Tockner and Stanford 2002, EEA 2016). Additionally, pollution from wastewater, industrial and agricultural sources increase the amounts of nutrients, pesticides, heavy metals, and more recently microplastics and pharmaceuticals, which are also deposited as polluted sediments (Wilkinson et al. 2022). Due to these multifactorial stressors, and their potential interaction (Stella and Bendix 2019), freshwater habitats are the most affected of all ecosystems, with wildlife populations declining by a global average of 83 % since 1970 (WWF 2018).

The interruption of longitudinal river continuity ultimately affects coastal areas e.g., through a lack of sediment influx, resulting in erosion and the retreat of certain sections of coastlines and their wetlands (Rodríguez-Santalla and Navarr 2021). The availability of sediment is gaining importance as coastal ecosystems face the additional threat of rising sea levels, leading to intertidal habitat loss due to fixed high-water marks and landward migration of low water marks, also known as "coastal squeeze" (see below). Although the response of coastal wetlands to rising sea levels during the 21st century remains uncertain, global scale projections suggest that between 20 % and 90 % (for low and high sea level rise scenarios, resp.) of the present-day coastal wetland area will be lost. If sediment is still supplied, then a wetland gain of up to 60 % can be expected, but without additional accommodation space, the loss of global coastal wetlands will range from 0 to 30 % by 2100 (Temmink et al. 2022, Saintilan et al. 2022, Schuerch et al. 2018). Wetlands are particularly vulnerable to climatic changes, as these will change the hydrological conditions that sustain them (Moomaw et al. 2018). In addition to rising sea levels, wetlands face climate-related threats due to changes in patterns of rainfall, changes in the frequency and intensity of droughts and storms, rising water temperatures, salt stress, a fall in the groundwater level and shifts in ecosystem engineer species etc.

Box 3: Coastal squeeze

The term coastal squeeze is commonly used to describe the loss of coastal habitats in front of sea defences (Pontee 2013) and is probably the main threat to the survival of coastal wetlands. It usually happens through the interaction of (i) coastal protection structures that create a static, artificial boundary between the land and the sea, and (ii) the concurrent accelerated rising sea level and other factors such as increases in storms that push coastal habitats landwards. Where the natural landward translation of a coastal wetland ecosystem is prevented, the habitat is “squeezed” into a narrowing zone (Doody 2012).

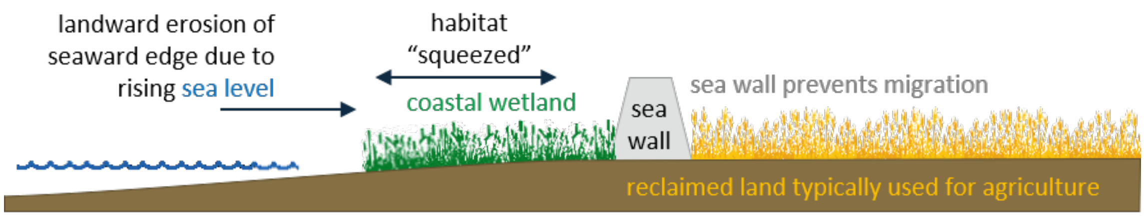

Figure 4: Coastal squeeze: landward mitigation prevented by the presence of a seawall

In summary, wetlands and their biodiversity have the capacity to adapt to the impacts of global change, but their ability to do so (i.e., their resilience) is reduced. Much of the remaining European wetland area is now heavily modified or degraded, making it even more vulnerable and less resilient to climate change, with many dependent species also threatened. Direct extraction, drainage and other human activities that affect the hydrological budget prevent wetlands from exercising their ecological function as hydrological buffers of droughts and floods and sites where groundwater becomes recharged. Unhealthy wetlands may not be resilient enough to recover from additional stressors. Extreme events have an impact on species and habitats, leading to changes in species richness, composition or sometimes (local) extinction or even the emergence of entirely new biological communities (e.g., Hobbs et al. 2006, Harris et al. 2020). Additionally, it is essential for wetland resilience that sufficient land is available to respond to changes in water level or temperature through migration or expansion.

2.3 Wetlands for climate change mitigation and adaptation

Riverine and coastal wetlands can provide essential nature-based solutions (NbS, see box below) for both the mitigation of and the adaptation to climate change. **Mitigation** targets the causes of climate change and refers to measures that reduce and curb greenhouse gas emissions and slow the rate of global warming, whereas **adaptation** addresses the impacts of climate change and refers to actions that help communities and ecosystems adapt to the effects already occurring or likely to occur.

Box 4: Nature-based Solutions (NbS)

Nature-based solutions are "actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits" (UNEA-5, 2022). This includes projects that protect or restore wetland ecosystems for climate change adaptation or mitigation, while providing biodiversity benefits (Sandin et al. 2022). A wide range of approaches can count as NbS, ranging from e.g., integrative river basin management that maintains the hydrological connectivity of floodplains to e.g., blue carbon projects that increase carbon sequestration in coastal wetlands.

The International Union for Conservation of Nature (IUCN) has developed an international standard for NbS which provides a set of eight criteria that can also be applied in wetland restoration projects (IUCN 2020). The standard is designed to ensure that NbS projects are ecologically sound, socially inclusive and acceptable, and economically viable. It promotes, for example, a participatory approach that ensures the inclusion of local communities and other stakeholders in the implementation process. This is critical to increase the scale and impact of the NbS approach, prevent negative outcomes or misuse, and helps funding agencies, policymakers, and other stakeholders evaluate the effectiveness.

As the continuing trend of loss and degradation will considerably exacerbate the problems that climate change will bring to nature conservation and people, NbS can provide cost-effective strategies for climate adaptation. They often make use of local resources and can be maintained over time at a lower cost than technological solutions, while offering major benefits for poverty reduction and biodiversity conservation.

2.3.1 Climate change mitigation: potential and success indicators

Both riverine and coastal wetlands can mitigate climate change by playing a key role in the global greenhouse gas budget. They are among the most effective natural long-term carbon sinks, storing carbon and preventing it from entering the atmosphere (Adhikari et al. 2009, Mitsch et al. 2013, Were et al. 2019). However, they can also be a source of greenhouse gases (GHG) especially when disturbed through human activities such as drainage or degradation from land use change (Taillardat et al. 2020, Whiting and Chanton 2001).

The complex role of wetlands as a source or sink of GHGs depends on multiple abiotic and biotic factors. Wetlands are sources of non-CO_2 greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) as a result of anaerobic decomposition of organic matter. While CH_4 is emitted at high soil water tables or from drainage ditches, higher N_2O emissions occur at lower or fluctuating water tables below the soil surface. In addition to the hydrological regime and water levels, the net flux is driven by the microbial community composition, vegetation, and the availability of nutrients. These factors can vary strongly in different wetland types, but also throughout the season and are significantly altered by rewetting, de-embankment, land use reclamation, slow rewetting, topsoil removal, harvesting and other restoration measures (e.g., Zak and McInnes 2022). Overall, wetlands are a complex and dynamic component of the global carbon C and N cycles, but a comprehensive and well-adapted management and a wise use of them can reverse the trend of wetlands emitting GHG and prevent emissions, and, in some instances, even promote carbon sequestration.

Box 5: Managing coastal wetlands as a nature-based solution for climate change mitigation – a Wadden Sea perspective

Even though they only represent 0.57 % of the oceans worldwide, the marine World Heritage sites and their immediate surrounding areas account for at least 21 % of the global area of blue car-bon ecosystems, with the carbon stocks there equivalent to about 10 % of annual global greenhouse gas emissions (UNESCO, 2018). One example of a region recognized for its blue carbon ecosystems is the Wadden Sea. It spans Denmark, Germany, and the Nether-lands and includes the world's largest tidal flats, which are composed of seagrass and tidal marshes. The following points outline several management options that can be implemented to increase carbon sequestration in salt marshes (Müller et al. 2019):

- Managing grazing pressure in existing marshes can lead to lower soil aeration, as well as an increase in belowground plant biomass, which can lead to greater rates of soil organic carbon stability and sequestration rates.
- Changing artificial drainage systems to natural systems can also help to increase soil organic carbon stability in existing marshes. By restoring the natural flow of water, it can help to create conditions that are more favourable for carbon sequestration
- Restoring tidal hydrology in embanked coastal areas that were previously marshes can suppress methane production and increase carbon sequestration.

While the role of trees in carbon sequestration has long been recognized, with a focus on their role in "green" carbon storage in forested floodplains (e.g., Cierjacks et al. 2010, Shupe et al. 2021, 2022) more recently the concepts of “blue” and “teal” carbon have emerged. Coastal wetlands are well-known for their capacity to sequester organic “blue” carbon, e.g., in seagrass meadows and marshes (as well as mangroves when looking beyond Europe), with extremely high sequestration rates per unit area, entirely due to C storage in sediments (Hopkinson et al. 2012). Due to their ability to sequester and store carbon, the importance of coastal wetlands for nature-based solutions for climate change mitigation is increasingly being recognized. Several management strategies can be used to enhance carbon sequestration, focusing on the conservation, restoration, and sustainable use of these ecosystems.

To evaluate the effectiveness of wetland protection and restoration as a climate change mitigation tool, measuring carbon sequestration in wetlands is an important aspect. Carbon sequestration refers to the capture of atmospheric carbon dioxide and its long-term storage in the soil, with minimal chances of being released back into the atmosphere (Were et al. 2019). Soil organic carbon stocks can be up to 800 t C/ha in the upper 1 m of organic soils of cold regions (Lal, 2004) and are determined by the balance of C inputs from primary production and losses through the decomposition of organic matter over time (Olson 1963). Thus, to quantify carbon sequestration, an analysis needs to consider the amount of carbon stored in the vegetation (biomass measurement), the carbon content in the soils (direct soil measurements) and the exchange of carbon dioxide between the wetland and the atmosphere, e.g., using towers equipped with sensors (Eddy covariance). A measurable increase in carbon sequestration over the medium term (after initial variability) means that a differentiation has to be made between soil organic matter and above-ground biomass, but only a few studies have considered the entire local carbon cycle (see review in Wantzen et al. 2022a). Furthermore, it is essential to measure the situation before and after the intervention or to use control sites to compare the carbon sequestration of degraded or previously disturbed wetlands with new or restored wetlands. It is likely that remote sensing techniques and satellite imagery in combination with artificial intelligence and machine learning algorithms will be increasingly used to monitor changes in vegetation and land use, and provide important information on the effectiveness of management strategies and conservation efforts (also for monitoring changes in the hydrology, which has an impact on carbon sequestration and for improving the accuracy of carbon sequestration estimates).

Figure 5: Salt marshes on the Wadden Sea, Germany. (Sources: left: Mathias Scholz, UFZ, right: Simone Wulf, BfN)

2.3.2 Climate change adaptation: potential and success indicators

NbS for climate change adaptation and disaster risk reduction (DRR) are essential in the face of multiple climate hazards that are occurring across different sectors of society and ecosystems (EEA 2021). The potential of riverine and coastal wetlands for providing these NbS and protecting people from climate change impacts is significant and diverse. For example, floodplains can reduce peak flood flows by delaying and storing floodwaters. Wetlands can also guard coastal ecosystems against saltwater intrusion when coastal freshwater bodies dry up. Moreover, coastal wetlands can slow down and dissipate the energy of incoming waves, due to their unique combination of vegetation, soils, and topography, and prevent coastal erosion. Wetlands International (2022) provides a comprehensive overview of wetlands services for climate change adaptation (see Table 1).

Tab. 1: Overview of wetlands services for climate change adaptation (based on Wetland international 2022, modified)

Climate Change Phenomena	Potential Impacts	Role of Wetlands in Climate Change Adaptation
Increased frequency and magnitude of freshwater floods	· Physical damage / loss of property and life and loss of ecosystems · Water pollution (overflow of sewage systems) · Water pollution (soil/sediment loss/ erosion) · Decreased (food) production through damage to production systems and agricultural areas	· Lakes and floodplains can reduce peak flood flows by delaying and absorbing floodwaters · Lakes and floodplains can detain polluted floodwaters · Highland peatlands can regulate river flows, releasing flood flows slowly over time
Increased frequency and magnitude of droughts (rising temperatures, periods with less rainfall)	· Decreased food production due to freshwater shortage · Waterways unavailable for transport · Cooling of power plants · Loss of ecosystems and biodiversity · Contamination of freshwater sources through saltwater intrusion	· Marshes, lakes and floodplains can maintain river base flows by releasing wet season flows slowly during drought periods · Groundwater aquifers can be recharged during water-rich periods, ensuring groundwater sources during drought · Income diversification during drought periods, providing alternative sources of food and water for people and biodiversity · Coastal wetland ecosystems can protect against saltwater intrusion when coastal freshwater areas dry up · Riparian forests can limit increases in water temperatures
Increased frequency and intensity of storms affecting coastal zones	· Physical damage / loss of property and life and loss of ecosystems · Pollution and damage to ecosystems and health · Decreased (food) production through damage to production systems and agricultural areas	· Coastal and delta ecosystems and reefs can disseminate storm power · Coastal wetlands such as salt grasslands or reeds can help local communities to recover their livelihoods after storms by providing sources of food and building materials · Forests and reefs can provide havens for biodiversity during and after storms

Melting of glaciers	· Increased floods after heavy precipitation in mountain regions, leading to floodplains · Less freshwater flows from glacier-fed rivers during periods with little precipitation, leading to freshwater shortages.	· Marshes and lakes can store excess precipitation, as glaciers did in the past · Marshes and lakes will release water in a reliable flow as glaciers used to do.

To assess the effectiveness of applied NbS from a climate perspective, the development of appropriate indicators, evaluation tools, and integrated assessment methods is necessary (EEA 2021). For example, for estimating the potential effects of different coastal features and management strategies at reducing wave energy, models like SWAN (Simulating WAves Nearshore), Xbeach, Delft3D, Wavewatch or MIKE 21/3 can be used. This involves simulation on the hydrodynamics, morphodynamics, and ecological processes of estuaries, coastal areas, and river deltas together with simulating the effects of vegetation and other coastal features on wave energy dissipation. For floodplains, the SWAT (Soil and Water Assessment Tool) can be used to evaluate the effectiveness of wetland restoration projects in increasing water storage capacity and reducing the impact of drought on downstream communities. To fully benefit from natural infrastructure, the effectiveness of wetlands as a climate change adaptation tool, together with benefits for biodiversity, tourism, recreation, fishing, and carbon capture and storage, needs to be recognized. This requires the use and the development of multiple and synergistic success indicators.

Figure 6: Floodplains reduce flood peaks by holding back floodwaters, Elbe flood, Germany, June 2013 (Source: André Künzelmann, UFZ).

2.4 Resilience-building solutions for riverine and coastal wetlands

In order to protect wetland biodiversity and to strengthen their resilience to cope with the impacts of climate change, it is essential to both reduce the vulnerability of the ecosystem and its species by removing pressures, restoring natural hydrological conditions, providing sufficient space, water and sediments, maintaining good ecological conditions, and protecting these habitats from further disturbance. It should be recognized that the ecological functioning of wetlands often depends on external factors outside of their boundaries (Friberg et al. 2016), hence any interventions should take the entire catchment scale into account.

In this context, the Ramsar Convention on Wetlands promotes the three approaches of wetland conservation, restoration and wise use (see below). As a prerequisite to implementing such measures, it is key to recognize the value of wetlands, their biodiversity and their contributions to people. Various methods and tools can be used to measure, map, assess, and report on the value of wetland ecosystem services (see e.g., Jähnig et al. 2022).

- **Conservation.** Protecting and conserving existing wetland ecosystems must be a priority. Protected areas, such as Natura2000 sites, biosphere reserves, national parks or wildlife refuges, can provide safe havens for wetland species, facilitate their migration to cope with changing climate conditions, and help to preserve their genetic diversity. The effective conservation of these areas often requires coherence and effective implementation of different policies (e.g. agriculture, flood management, biodiversity, etc.) both inside and outside the protected areas themselves. In the long-term, the management of protected areas needs to take future climate change scenarios into account.
- **Restoration.** Wetland restoration can involve a variety of approaches along the so-called restoration continuum, with the eight international principles of ecological restoration (Gann et al. 2019), which include protecting biodiversity, enhancing human health and well-being, improving food and water security, promoting economic prosperity, and supporting climate change mitigation and resilience. It also involves engaging communities, scientists, policymakers, and land managers in the process of repairing ecological damage and fostering a healthier relationship between people and the natural environment. Approaches range from small improvements of ecological status to the full restoration of lost or new wetland ecosystems. It includes actions such as re-establishing natural morphological activity, improving hydrological connections between wetlands and their river basins, recreating wetland habitat (e.g., through managed realignment of dams), restoring the sediment flux at the river basins to reach the coast, and reducing pollution or other negative pressures. To reach certain restoration goals, adaptive management is crucial. It is also necessary to recognize that, depending on the initial degradation of the restoration site, a fully natural state and species composition might not be achieved, even after decades.
- **Wise Use.** The wise use of wetlands means balancing the need to maintain their ecological purpose with the need to use them for human benefit in a sustainable manner. This involves implementing sustainable practices that minimise the impact of human activities on these ecosystems (e.g., sustainable tourism), while maximising the benefits that can be derived from them. For some types of wetlands, it needs to be acknowledged that they can fulfil their ecosystem functions only if there is no direct use at all.

Strengthening existing legal and regulatory frameworks, or developing new ones, can help to ensure that wetland ecosystems receive the protection and sustainable management they need to maintain their health and resilience. Besides suitable political and regulatory framework conditions, resilience-building solutions rely on various factors, such as the availability of (undeveloped) land, the integration of available knowledge into planning and decision-making processes, capacity building as well as sufficient funding.

Furthermore, social factors are also crucial. Improving stakeholder commitment, participation and awareness of the importance of these ecosystems helps to enhance acceptance and implementation (see e.g., Gapinski et al. 2021, 2022). This might also require a change in the perception of flooding, not only as a threat but also as a positive element and essential feature of natural water bodies (Serra-Llobet et al. 2022). The goal-oriented project management and constructive cooperation of all participants are essential for the success of any project.

No single strategy on its own will be sufficient to protect and restore wetland biodiversity from the impacts of climate change and other threats. Instead, combinations of approaches are imperative. It all starts with an acknowledgment that aspects of wetlands (species compositions, species interactions, ecosystem functions) will inevitably change under climate change. It is important to consider what changes for wetlands might look like. Possible trajectories are to resist change and try to maintain the existing composition, structure and function of the ecosystem, to accept change (if resistance is not possible or if change is considered socially acceptable) or to direct change towards a future ecosystem configuration that leads to desirable outcomes ("Resist-Accept-Direct" framework, see e.g. Thompson et al. 2021).

Answers will always need to be more local than general, as the best solutions will vary depending on the specific wetland ecosystem in question and the threats it faces. Understanding and identifying the individual drivers of change for different types of wetlands is one of the challenges in developing and implementing effective measures for improving their resilience, as well as harnessing their potential as NbS where suitable.

The following chapter will focus on the practical implementation of restoration measures for biodiversity and climate in riverine and coastal wetlands.

Figure 7: Example of a small renaturation measure: development of an island after installing deadwood, Ruhr, Germany (Source: Kathrin Januschke, UDE)

3 Wetland restoration in practice

The Ramsar Convention on Wetlands describes wetland restoration in a wider sense, encompassing both efforts to bring a wetland back to its previous state, as well as aiming to enhance its functioning without necessarily achieving its pre-disturbance condition (see Handbook 2019 by Ramsar Convention Secretariat 2010). This definition coincides with the ten principles for the UN decade of ecosystem restoration, which include involving all stakeholders, prioritizing prevention, focusing on ecosystem health, promoting equitable governance and benefit sharing, and recognizing the importance of traditional knowledge and practices (UNEP 2021), in line with the eight international principles of ecological restoration (see 2.4).

In recent decades, there has been a tremendous improvement in the understanding of biogeochemical drivers and processes in wetlands (Walton et al. 2020). Additional experiences from monitoring wetland restoration projects have enabled us to derive some robust scientific principles for understanding the implications of actions and optimising restoration measures (e.g., Schulz-Zunkel et al. 2022). To be genuinely successful, the restoration of severely degraded wetlands depends on ensuring that benefits are optimised and distributed across multiple sectors of society. Wetland conservation and restoration efforts can create various benefits beyond climate and biodiversity, for instance in the field of water security, nature tourism and sustainable development (so called co-benefits) which need to be considered and targeted (Knight et al. 2017, Soto-Navarro et al. 2020, Pindilli 2021). However, this multidimensional character can also pose a challenge in understanding, mapping, and communicating project objectives, for which integrated approaches are urgently needed. Moreover, holistic and systemic approaches need to be pursued to account for trade-offs and minimize any potential negative consequences (Everard and McInnes, 2013).

Specifically, large-scale water management strategies are required to restore the hydrological and ecological character of wetlands. This involves, for example, the cutback of dikes to enable flooding or the reactivation of sidearms for rewetting. However, wetland restoration and management can also involve technical small-scale measures such as tree removal, changes in land-use and agricultural measures, such as modified cropping techniques (Arneth et al. 2021). They have the potential to simultaneously improve the hydrological regime of degraded wetlands and the overall habitat quality. Creating artificial or constructed wetlands in urban areas can also contribute to reduced floods, improved water quality, habitats and landscapes (Stefanakis 2019).

In Europe, a wide range of wetland restoration activities have been applied. LIFE[2] is one of the main EU financial instruments, supporting environmental, nature conservation and climate action projects throughout the EU. Furthermore, Wetlands International[3] as well as other organisations have been implementing wetland restoration projects. Around the Mediterranean, MedWet[4] has been implementing various projects. A selection of notable wetland restoration projects in Europe can be found in Annex A.

[2] Public database of LIFE projects: http://ec.europa.eu/environment/life/project/Projects/index.cfm
[3] Homepage of Wetlands International: https://europe.wetlands.org/
[4] Homepage of the Mediterranean Wetlands Initiative: https://medwet.org/

3.1 Key barriers to scaling up wetland restoration in practice

"The three most important [barriers are ….] insufficient funding, conflicting interests among different stakeholders, and low political priority given to restoration." (Cortina-Segarra et al. 2021).

Wetland restoration is often opportunity-driven, but opportunities vary. In parts of Central and Eastern Europe where population densities and agricultural intensification rates are relatively low, opportunities can arise to restore areas of former wetlands on suboptimal farmland. However, in other areas of Europe, such as in the UK, the Netherlands, and Southeast Europe, where the pressure on land is very high due to population densities and intensive agriculture, restoring wetlands is more challenging due to limited opportunities and fragmented efforts. In southern Europe, additional challenges arise due to regional water scarcity.

Thus, wetland restoration has often been conducted on a small-scale project-by-project basis with time-limited funding (Moss and Monstadt 2008). Nonetheless, to slow the progress of climate change and to adapt its most harmful effects in an effective and sustainable way, there is an urgent need to significantly scale up efforts through economic incentives and community support for the large-scale restoration of wetlands.

Besides insufficient funding, fragmented and little coordinated restoration, challenges from conflicting land uses, limited land availability, and lack of public acceptance need to be overcome. Addressing these barriers requires a multifaceted approach that involves government-, private sector- and community stakeholders and an implementation of policies and regulations that support wetland conservation and restoration.

Based on expert perspectives, different barriers for an effective ecological restoration were identified. As shown in the table, wetland restoration is faced with challenges from a wide range of interests and institutional mechanisms, including agricultural production, water protection, nature conservation, flood defence, navigation, recreation, urban and rural development, and the protection of historical landscapes.

Tab. 2: Overview of the barriers for ecological restoration in wetlands: Results of the expert workshop

Type	Barrier	Description / Example
Ecological	Spatial scale	• Wetlands often span multiple private and public ownership boundaries / administrative boundaries and are influenced by processes throughout their (often extensive) catchment areas
	Ecological Complexities	• Complex and disturbed interrelationships (e.g. limited connectivity) control presence or establishment of local species and habitats, e.g. limited connectivity
	Temporal Scale	• Ecological timescales of ecosystem recovery can span decades and rarely correspond to timescales for organisational planning and funding
Implementation (execution)	Assessments and data	• Limited data available for project planning • Limited evaluation, monitoring and documentation to assess effectiveness and inform future restoration efforts • Knowledge and understanding of wetlands on different scales can be quite different - national-scale models might be invalid at the local scale and vice versa

		• Smaller scale pilot efforts cannot realistically demonstrate the full range of benefits from large (river basin) scale restoration
	Implementation and Management	• Conflicting land uses (urban development, agriculture, resource extraction) through lack of integrated land-use-planning • Lack of standards and relevant experience • Lack of enabling policy instruments • Lack of skilled personnel for project implementation • Uncertainty regarding future developments and climate change impacts (need for adaptive planning and high flexibility)
	Poor Coordination	• Difficult coordination if wetland restoration crosses political and administrative boundaries with multiple departments and agencies involved • Lack of a legitimate institution that is capable from a financial, legal and man-power perspective of carrying out the projects
Financial	Insufficient funding	• Lack of funding for large-scale implementation of restoration measures • No money for e.g., monitoring to test the success of restoration • Personnel resources / capacities are needed especially for large-scale projects
	Opportunity Costs	• Sufficient compensation for agriculture, urban development, or industrial uses might be required
	Misplaced Subsidies	• Subsidies for agriculture leading to conversion of wetlands to cropland
Social	Acceptance and Education	• Uncertainty about the benefit to society and the urgency of the problem in its entirety: Value of wetlands may not be well understood or appreciated by the general public • An overall negative perception of wetlands in some cultural frameworks or even a lack of visibility of these environments by society • Perception of floods as dangerous and not as essential, the value of wetlands in the context of climate change may not be recognized • Public opinion puts more trust in technical solutions compared to NbS • Difficulties to understand uncertainty involving ecosystem management decisions (e.g., there is not a "cook-book" applicable to any situation) • Lack of effective knowledge exchange or unwillingness to admit that e.g., past practices were unsustainable
	Conflicts of interest	• Conflicts between agricultural land use (or e.g., forestry, fisheries) and nature restoration • Conflicts between urban / infrastructure development and nature restoration • Conflicts between water management / coastal management and nature restoration • Conflicts between tourism development (e.g., hotels along the coast) and nature restoration (although synergies with nature tourism are also possible) • Competition with other land uses as bottlenecks that most often impedes the restoration process
	Lack of Participation	• Limited stakeholder commitment and lack of participation • Stakeholder involvement too late in the project planning phase • Insufficient communication and information with local residents • Insufficient time and resources available for true co-creation processes

Policy	Complexity	• Administrative contradictions or boundaries / bureaucracy barriers e.g., between water management and nature conservation • Inflexible legislation as well as conservative nature protection (not open to new ways or adaptive management)
	Priority	• Wetland restoration not seen as a pressing political issue (low priority) resulting in lack of funding, resources and political will to support wetland restoration and conservation efforts
	Unsuitability / Inconsistency	• Policies that do not consider the ecological values and functions of wetlands, or promote activities that lead to wetland loss and degradation
	Property rights	• Lack of agreements and permissions to carry out restoration work (especially when privately owned) • Obtaining the necessary land and property rights for restoration and conservation is complex and time-consuming
	Spatial Scale	• Gap between (inter)national goals and local support and financing

Figure 8: Room for the river Waal - Reconstruction of a new river arm, protecting the city of Nijmegen, The Netherlands (Source: Mathias Scholz, UFZ)

3.2 Recommendations for overcoming barriers and realizing synergies

The task of restoring riverine and coastal wetlands poses multi-dimensional challenges to policy-makers and project managers (Figure 9). Various stakeholders must be involved as early as possible, i.e., from the diagnosis phase, when the need and objectives for a restoration project are defined. This also allows the early identification and integration of local interests into the project plan to avoid trade-offs and maximize co-benefits, for example by maintaining accessibility of the restoration site for recreation and sustainable tourism (see e.g., Wulf 2021). Active engagement, and ideally project ownership by local residents and authorities is crucial, and political backing and funding from regional, national, and supranational agencies is essential for success (Gapinski et al. 2022). The competence and leadership of those responsible for the project also play a key role in its success. Decision making for wetlands is not just about reaching an agreement on a specific plan or design, but rather a long-term continuous process of guiding a scheme through planning, funding, implementation, and post-evaluation stages. This adaptive management cycle is not linear, but rather a set of iterative loops that may include setbacks, delays, breakthroughs, and re-negotiations (Moss and Monstadt 2008, Langhans et al. 2019a).

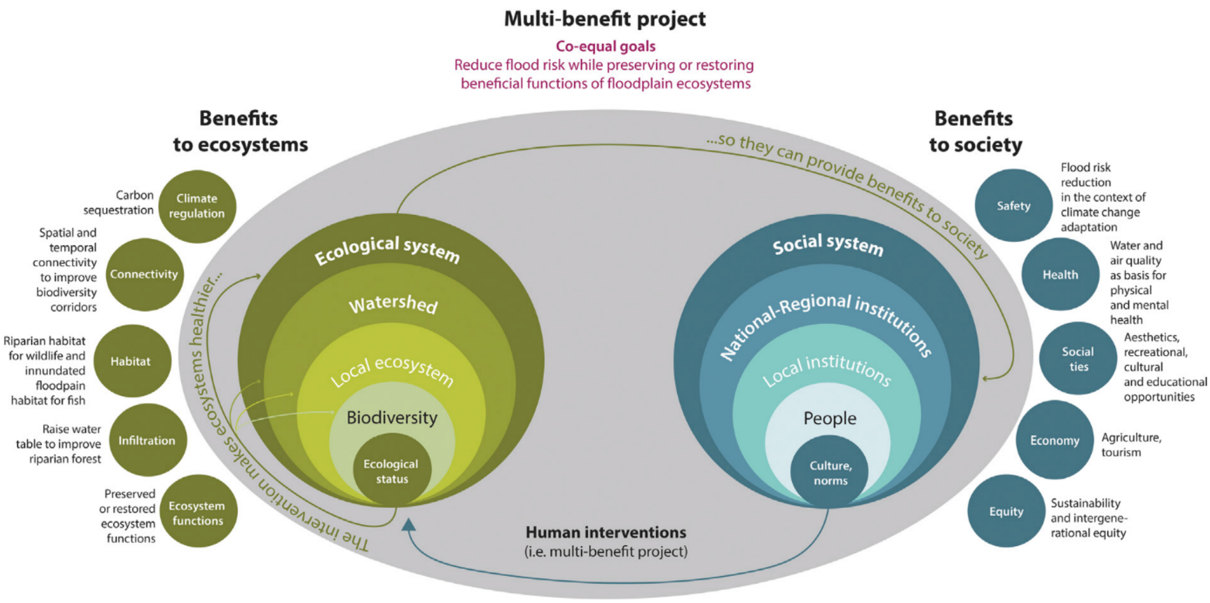

Figure 9: Conceptual diagram of the role of multi-benefit projects in the context of social-ecological systems for riverine wetlands (Source: Serra-Llobet et al. 2022; applies in large parts also to coastal wetlands)

Communication and management are important success factors for the implementation of restoration measures. This includes bridging the science-policy-society gap and the barrier between scientists of different disciplines. Natural scientists and social scientists need to be open about collaborating on socio-ecological wetland research, and scientists and stakeholders need to exchange knowledge more effectively (Yousry et al. 2022, Urbanič et al. 2022, Wantzen 2022). Finding a balance between bottom-up (participatory) and top-down (governance) approaches is also necessary. In addition to the transfer of technical skills, it is crucial to learn from successful projects and identify social-decision patterns that are common to specific types of projects. These patterns can then be applied to similar projects (see, e.g., Wantzen et al. 2022b, Langhans et al. 2019b, Wulf 2021). Defining concrete monitoring and assessment tools is an essential step in identifying synergies and formulating key recommendations for realising synergies to overcome the main barriers to ecological restoration of wetlands in Europe.

Based on expert perspectives several recommendations for effective ecological restoration were identified that consider financial, social, knowledge and policy aspects (see Table 3).

Tab. 3: Overview of recommendations for effective ecological restoration in wetlands: Results of the expert workshop

Type	Recommendation Example or Concrete Tool
Financial	***Create and redesign incentive schemes for land use and development (Bonus & Malus) that reflect the value of wetlands and the opportunities and benefits of NbS.*** • Motivate farmers to participate in restoration projects e.g., by purchase or exchange of land (create state-owned pools of land for such exchanges by public purchase of available farmland) • Introduce payments for ecosystem services that can partially solve the problem of externalities and the upstream-downstream paradox. • Make use of favourable economic contexts for restoration, e.g., where maintenance of old dikes or continued drainage of wetlands for agricultural use already incurs high costs due to peat mineralization or soil subsidence (e.g., Peene valley in Germany) • Use money from industry and companies offering compensation funds for e.g., CO_2 emissions to apply restoration or sell carbon certificates

	Unlock sufficient resources (skills) and funding (money) to meet the complex social-ecological challenges of wetlands restoration: knowledge, planning, implementation, monitoring and evaluation, adaptation.
	• Embed ecological wetland restoration into EU funding programs e.g., the 2021-2027 Multiannual Financial Framework (MFF), including the EU's LIFE program, the European Agricultural Fund for Rural Development (EAFRD) and the European Regional Development Fund (ERDF); EU research and innovation program Horizon2020, the EU initiative European Green Deal, the Common Agricultural Policy CAP, etc. with the following goals:
	  · to involve major private companies in industries (energy, agriculture, conservation),
	  · to create tax breaks and compensation for ESS,
	  · to oblige developers to allocate funds for wetland restoration as compensation for land and resource use
	  · to foster strong public-private partnerships
	  · to ensure long term / sustainable funding instead of short-term funding

Social	***Strengthen the participation and the commitment of all relevant stakeholders from the entire river basin throughout all phases of the restoration process (planning, design, implementation) to avoid conflicting objectives.*** • Communication is key. Develop communication strategies at different levels by e.g., providing toolkits for agricultural advisors or town planners. Identify the right audience to communicate with to foster implementation • Mitigate conflicts among stakeholders by nonmonetary visualization of ESS and their uses • Involve stakeholders as soon as possible (i.e., in diagnosis phases) and take their interests and priorities into account. • Foster exchange and transdisciplinary perspectives by also involving political decision-makers in the projects or the development of restoration programmes. Promote knowledge sharing and communication of best practices by local ambassadors (e.g., through exchange platforms, respecting landowners and other stakeholders) and build strong relationships. • Create alliances of NGOs to support advocacy/communication for wetland restoration. • Provide incentives such as direct economic opportunities (jobs!) for local communities in the context of wetland restoration. • Citizen science: Members of the public participating in collecting and analyzing scientific data is a valuable and cost-effective tool for gathering data but also for increasing public awareness and participation, providing valuable insights into the social and economic aspects. • Allocate funds for actions or specific institutions that bring together the various stakeholders.

	Emphasize the benefits that wetland restoration brings to the ecosystem and society. • Nature connectedness and intrinsic motivation is key. Provide practical experiences through excursions and hands-on activities ("get people wet") to connect people with wetlands through emotional appeals. • Education is important. Foster cultural connections with rivers and coasts through education, starting with children and extending to farmers. Include wetland restoration in school education programs. • It is imperative to deepen the understanding of why wetlands matter. Transdisciplinary approaches, e.g., methods from ESS assessments (see box below), and the linking of these to the socio- economic benefits of wetland restoration are useful.
Knowledge	***Create good practice guidelines for ecological restoration that can be adapted to specific conditions, and regularly update them through evaluation and monitoring, while also documenting restoration projects and promoting adaptive management.*** • Learn from others through demonstration sites (e.g., Ramsar case studies), living labs and the power of positive examples. • Fill knowledge gaps (e.g., more data on nutrient cycling) to create comprehensive databases. Connect them with good practice examples. • Report the success of applied restoration measures (social and economic indicators) to develop an indicator-combination of different assessment approaches aiming at multiple benefits. Here, one can also learn from other big projects from e.g., industry to imitate strategies for advertising and other marketing restoration benefits.
Policy	The following chapter focusses on appropriate action on regulations and policies that are in line with the proposed measures above (e.g., the planned EU Nature Restoration Law), as well as engaging and working with political decision-makers, to ensure that wetland restoration receives a sufficient level of priority and resources.

Box 6: Lessons learnt from implementation exemplified by the IDES - Project Improving the water quality of the Danube River and its tributaries through integrative floodplain management based on Ecosystem Services

The IDES-Project implemented an ecosystem service (ESS) approach in five pilot areas (the Danube, Mura, and Tisza floodplains) to identify effective NbS for several river and floodplain issues regarding the environment and society (Stäps et al. 2022). Next to scientific indicator-based methods to assess the current status of various ESS, **the local specificities and the stakeholders' perception were the main ingredients for the development of water management concepts** in these pilot areas. Two workshops were conducted where all relevant stakeholders of a pilot area ranked the importance of ESS, pressures, and possible measures using the DPSIR (drivers-pressures-state-impact-response) framework. Participants demonstrated an impressive understanding of their floodplain ecosystem and developed a fuzzy cognitive model to estimate impacts on ESS and identified optimal scenarios with the highest synergies and lowest trade-offs for society and ecology. This process enabled co-created water management concepts to be developed for the five pilot areas. IDES thus developed and tested a harmonised approach for the entire Danube basin that incorporates local interests and knowledge into decision-making. Furthermore, this harmonised approach enables the identification of restoration potential and deficits in ESS provision on a large scale (the river basin).

4 Wetland policy and governance: how to move forward in Europe

4.1 Policies supporting the restoration and sustainable use of wetlands

Wetlands are impacted by a wide range of international and European policies, as summarized in Figure 10. Some affect them directly, while others influence the management of the wider landscape surrounding them. At the same time, the restoration of wetlands can also contribute to a range of environmental policy goals (e.g., biodiversity, climate, and water targets).

Figure 10: Policies relevant to European riverine and coastal wetlands.

4.2 Synergies and conflicts regarding the different policy sectors

The interaction between wetland-related policy objectives such as managing flood risks, reaching or maintaining a good ecological status of water bodies, ensuring water and food security, increasing carbon sequestration and safeguarding biodiversity and ecosystem services is complex, especially in the context of climate change. Riverine and coastal wetlands are often at the intersection of multiple legislative and administrative frameworks, including agriculture or other land uses, transport, industry, housing, water quality and quantity management and nature conservation. This leads to conflicts but also potential synergies between policy sectors (e.g., Urbanič et al. 2022).

EU Policies have already made efforts to address wetland-related issues, but often with a sectoral approach. The 2000 EU Water Framework Directive and to some extent the 2007 Floods Directive provided the first overarching frameworks, encouraging member states to move towards thinking more globally about water resources on a catchment level and motivating some countries to think about natural flood management measures. The 1992 EU Habitats Directive affords protection (through the establishment of the Natura 2000 network of protected sites) for a range of wetland related habitats and the species reliant upon them. While the Nature Directives have been judged to be effective (SWD 2016), some issues with coherency with other policy objectives (e.g., water, floods, marine, and climate change) were identified. In particular, the terminology and timeframes of the different directives are not coordinated.

Integrated approaches for systematically assessing and harnessing the various benefits of ecosystem restoration have been pursued for some time in both science and policy. Related terms include Ecosystem-based Approaches (EbApr), Nature-based Solutions (NbS), Natural Water Retention Measures (NWRM), Integrated Coastal Zone Management (ICZM) and Green and Blue Infrastructure (GBI). Efforts to standardise the terminology include the launch of a Global Standard for NbS by the International Union for Conservation of Nature (IUCN 2020). The standard aims to provide a solid basis for defining and implementing NbS (as an umbrella term for the beforementioned concepts), to ensure sufficient social and ecological safeguards and to promote monitoring mechanisms that are adaptable to local contexts. The term NbS has also been officially defined through a resolution of the United Nations Environment Assembly (see box in Chapter 2). On the global level, NbS are promoted by Target 8 and 11 of the new Global Biodiversity Framework of the Convention on Biological Diversity.

At the EU level, the EU Biodiversity Strategy for 2030 and the proposal for a new EU Nature Restoration Law (see following chapter) aim to foster NbS for climate change mitigation and adaptation through the large-scale implementation of nature restoration measures, e.g., including the target of restoring 25,000 km of free-flowing rivers by 2030. In terms of climate policy, the EU Strategy for Adaptation to Climate Change explicitly promotes the implementation of NbS for adaptation, and other Green Deal policies have also explicitly recognized the importance of NbS for climate change mitigation.

However, other cross-sectoral policies that recognize the overlaps between climate and biodiversity and bring together socioeconomic and political interests are still needed.

A prominent example of how these overlaps need to be improved is the Common Agricultural Policy (CAP) which provides the main EU funding mechanism for all agricultural activities. It has been criticised over its history for having negative impacts on wetlands and the environment (e.g., Marsden and Jay 2018, Pe'er et al. 2019). In its initial form, in order to increase food production, the CAP directly funded the draining of wetlands to convert them into more productive forms of farmland as well as encouraging more intensive practices, including the use of pesticides and fertilisers (Donald et al. 2002). This led to the destruction of valuable wetlands and the loss of their valuable ecosystem services, such as water storage and flood protection, and contributed to the pollution of water sources and loss of aquatic species.

Agri-environment measures were first added voluntarily to the CAP in 1985 and since then, through various reforms, the CAP has come to have multiple environmental, social and economic targets (Batáry et al. 2015). In the latest versions of the CAP, there is a growing emphasis on these environmental and social objectives alongside agricultural productivity. However, the CAP still aims to support agricultural production and competitiveness, while promoting sustainable land management practices and protecting the environment. Reviews for the Commission services have repeatedly shown that monitoring is not sufficient to show the impacts of the CAP on these policy areas and that objectives targeting the aquatic environment are not integrated systematically enough by member states into their general objectives (see EC, 2022). First assessments suggest this is unlikely to change in the latest CAP iteration which gives member states significant flexibility as to how to implement the policy (EEB, BirdLife 2022).

Another example for a policy sector with the potential for both conflicts and synergies with nature restoration is the field of coastal protection. Typical coastal protection policies focus on building sea walls or other technical structures to protect human populations and infrastructure from coastal erosion and flooding. This generally limits the available space for coastal wetlands and hinders natural dynamics. However, synergies between wetland restoration and coastal protection are also possible, for instance in situations where existing hard defence structures are costly (or impossible) to maintain or fortify against rises in sea levels in the long term, especially when they are primarily protecting agricultural land. In this case, it can be cost-effective to implement a managed realignment project, opening the old dike to restore coastal wetlands in the formerly drained lowland areas, while constructing shorter, well-maintained defenses further inland around affected settlements (e.g., along the German Baltic coast, see Wulf 2021). The restored wetlands might even contribute to extending the lifetime of adjacent coastal defences, through attenuation of wave energy or the regulation of sediment flows (see Borsje et al. 2011). While some nations have already embraced the rationale of managed realignment as an NbS for climate change adaptation (e.g., in the UK), there is still great potential for further integrating coastal NbS into national coastal protection policies in Europe.

Overall, there remains a substantial need for improving policy coherence and for bringing NbS further into both mainstream EU and national policies in order to foster synergies for biodiversity and climate (EEA 2021), especially with regard to wetland ecosystems.

4.3 Upcoming EU nature restoration policies

A significant and transformational policy change is therefore needed to effectively support the restoration and sustainable use of wetlands. This requires the development and implementation of comprehensive legal frameworks and financial incentives to support restoration efforts. A first move in this direction can be seen in the proposed EU Nature Restoration Law (COM 2022). The proposal has binding targets to restore degraded ecosystems (20 % of the EU land and sea area by 2030 and all ecosystems in need of restoration by 2050). It focuses in particular on those ecosystems with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters. The proposed law lists the habitats of greatest importance for restoration. Thanks to their high importance for both water management and climate, the focus is on terrestrial, coastal and freshwater ecosystems (article 4), as well as the natural connectivity of rivers and the natural functions of their floodplains (article 7). Specific targets building on existing legislation (including the Nature Directives) are proposed for the different habitat types. Moreover, member states will be required to produce national restoration plans with concrete proposals on the areas to be restored. If fully implemented, the proposed regulation would have a significant impact on the restoration and conservation of wetlands across the EU.

Certain member states have already taken concrete steps to put their own restoration plans for wetlands in place. In Germany, an ambitious action plan for nature-based solutions for climate and biodiversity (Aktionsprogramm Natürlicher Klimaschutz, ANK) was published in March 2023, backed by a 4 billion Euro funding program (BMUV 2023). This partly builds upon a range of existing funding programmes for nature conservation, such as the Federal Programme on Biological Diversity or the river and floodplain restoration programme “Germany’s Blue Belt”, among others. The measures of the new ANK action plan are organised as ten action fields, according to habitat type, with one chapter focusing on rewetting peatlands, one on restoring rivers, lakes and flood plains, and one on seas and coasts.

To name just a few other examples, Spain has launched a Strategic Plan for Wetlands for 2030 and a national Strategy for Fluvial Restoration in 2022, building on previous efforts initiated by implementing the Water Framework Directive. Their goals include making at least 25000 km of rivers free-flowing again by 2030. Switzerland has committed to restoring 4000 km of rivers and streams in the revision of its Swiss Water Protection Act in 2011, while France has launched its fourth National Action Plan on Wetlands in 2022, including various conservation and restoration targets. It can be expected that the upcoming EU Nature Restoration Law will add further momentum to such existing national endeavours for wetland restoration.

Figure 11: Grazing management with rebreeding of the extinct auerochs, restored Lippe river floodplain, Klostermersch, Germany (Source: Hans D. Kasperidus, UFZ)

5 Conclusion: How to integrate science, policy and practice

There is an urgent need to scale up action to protect, restore and sustainably manage riverine and coastal wetlands in Europe. Such efforts are necessary to increase the resilience of wetlands in the face of climate change, as well as to safeguard their manifold ecosystem services, including their valuable contributions to biodiversity conservation, climate change mitigation and adaptation. To succeed, it is crucial to improve the integration of science, policy and practice for wetlands even further.

Science provides the evidence base for understanding the ecological, economic, and social benefits of riverine and coastal wetlands, their vulnerability and the impacts of various human activities on wetland ecosystems. Policy provides the legal and administrative frameworks for guiding and supporting conservation and management efforts, as well as promoting cross-sector collaboration and policy coherence. Practice involves the implementation of conservation and management actions on the ground, including links between coastal protection, water management, land use, climate action and nature conservation.

Over the past 30 years, the European Commission has published several strategies aimed at safeguarding Europe's natural resources and removing any obstacles on the path of an ecological improvement of European wetlands. Initiatives such as the EU Biodiversity Strategy for 2030 and the proposed EU Nature Restoration Law have great potential for fostering large-scale restoration measures in the near future. The involvement of a wide range of stakeholders, including land users and authorities from various policy sectors will be imperative as national restoration plans are developed and implemented. Moreover, social and economic analyses should be included to consider all of the potential effects of restoration, to maximize co-benefits and to convince (local) decision-makers. By involving those who have been impacted directly in restoration efforts (e.g., rural land users) at an early stage is key to enabling social acceptance and to successfully implementing the respective policies. Ensuring the long-term availability of funding is another success factor, given that restoration processes are ecologically complex and can span long time-scales.

While the great political momentum for nature restoration in Europe is promising, it is just as important to also scale up efforts to prevent the destruction of remaining intact wetland ecosystems, halting their further degradation and boosting their resilience.

From a scientific point of view, it is crucial to quantify the vulnerability and functioning of European riverine and coastal wetlands in an integrative way. Therefore, a combination of different approaches should be used to consider multiple indicators of ecosystem health and functioning (e.g., Piskol et al. 2022). To ensure consistent and comparable results across different studies and regions, there is a need to further develop standardised methods and suitable protocols for a time- and cost-effective assessment and monitoring, building on existing approaches (e.g., German Floodplain Report, Koenzen et al. 2021). The applied methods should be able to take into account the diversity of local contexts in terms of both the ecosystems targeted and the pressures exerted.

To identify best management practices for wetland areas, a wide range of data would help to inform flexible and adaptive approaches in practice, taking natural dynamics and future climate change impacts into account. Possible data sources for an overall assessment include quantitative, qualitative and temporal information on habitat changes at high spatial resolutions, e.g., based on remote sensing or field data, as well as modelling tools to describe e.g., the hydrological regimes in wetlands and climate change scenarios. Moreover, social and economic indicators should also be monitored (e.g., visitor numbers as an indicator for the use of restoration sites by tourists). Awareness must still be raised that without proper monitoring and evaluation, it is difficult to determine whether restoration efforts are achieving their goals, to prevent wasted resources and unsuccessful outcomes, and to enable the development of good practice and enhance adaptive management.

In order to scale up action for wetlands, increased global visibility and awareness of the important roles they fulfil is necessary. This, too, could be fostered through the exchange of actors from science, policy and practice, as joint narratives are developed and communicated. To achieve co-benefits and synergies in practice, it is important to prioritise social learning and provide adequate time, early stakeholder involvement, and careful attention to process management. Successful implementation of any institutional development also requires sufficient human and institutional capacity at the right time and place. To create synergies between policies, early cooperation, negotiation, and flexibility can help to improve coherence and avoid overlap between various programs.

The EU Nature Restoration Law will be a major step forward in meeting the future challenges of climate change impacting riverine and coastal wetlands. It will also help to mainstream wetland-focused nature-based solutions for biodiversity and climate in Europe.

Box 7: European conference on riverine and coastal wetlands for biodiversity and climate: Linking science, policy and practice

Since 2011, the German Federal Agency for Nature Conservation (BfN) has been organising a series of "European Conferences on Biodiversity and Climate Change" in cooperation with the European Network of Heads of Nature Conservation Agencies (ENCA Network). The aim of the conference series is to strengthen the interface between science, policy and practice and to promote exchange and networking between respective experts from all over Europe. Due to the high importance of riverine and coastal wetlands for biodiversity and climate change, the 5th conference in this series will focus on their role in climate change adaptation, mitigation and biodiversity conservation. The conference aims to bring together scientists, policy makers and practitioners, in order to foster the transdisciplinary exchange of experience on the impacts and roles of wetlands for biodiversity and climate, to raise awareness of their importance and to develop recommendations for action.

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Abbreviation	Explanation
AKN	Aktionsprogramm Natürlicher Klimaschutz Federal Action Plan for Nature-based Solutions for Climate and Biodiversity
BfN	Bundesamt für Naturschutz German Federal Agency for Nature Conservation
BMUV	Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CC	Climate Change
DRR	Disaster Risk Reduction
EbApr	Ecosystem-based Approaches
ENCA	European Network of Heads of Nature Conservation Agencies
ESS	Ecosystem Services
GBI	Green and Blue Infrastructure
GHG	Greenhouse Gases
ICZM	Integrated Coastal Zone Management
iDiv	Deutsches Zentrum für integrative Biodiversitätsforschung German Centre for Integrative Biodiversity Research
NbS	Nature-based Solutions
NFM	Natural Flood Management
NWRM	Natural Water Retention Measures
UFZ	Helmholtz-Zentrum für Umweltforschung GmbH Helmholtz Centre for Environmental Research
WFD	Water Framework Directive

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A Appendix 1: Selected notable European wetland restoration networks and projects in Europe

Project Synonym	Project Title	Project Duration	Project Website
Bio Agora	Connecting research results on biodiversity to the needs of policy making in a targeted dialogue between scientists, other knowledge holders and policy actors	07/2022 - 06/2027	https://bioagora.eu/
Crosslink	Riparian Buffers: Learning and Tools	12/2016 - 01/2020	https://www.riparian buffers.com/
Danube 4all	Restoration of the Danube river basin waters for ecosystems and people from mountains to coast	01/2023 - 12/2027	in progress
Danube Floodplain	Reducing the flood risk through floodplain restoration along the Danube River and tributaries	06/2018 - 11/2020	https://www.interreg-danube.eu/approved-projects/danube-floodplain
DRE	Dam Removal Europe	01/2014 - 12/2020	https://damremoval.eu/
FLUVIAL	Improvement and sustainable management of river corridors of the Iberian Atlantic region	09/2017 - 12/2022	https://www.life fluvial.eu/en/
IDES	Improving water quality in the Danube river and its tributaries by integrative floodplain management based on Ecosystem Services	07/2020-12/2022	https://www.interreg-danube.eu/ides
Irekibai	Improving connectivity and habitats in rivers	07/2015 - 12/2020	https://www.irekibai.eu/en/
MERLIN	Mainstreaming Ecological Restoration of freshwater-related ecosystems in a Landscape context: INnovation, upscaling and transformation	10/2021 - 09/2025	https://project-merlin.eu/
PONDERFUL	POND Ecosystems for Resilient Future Landscapes in a changing climate	12/2020 - 11/2024	https://ponderful.eu/
REST-COAST	Large scale RESToration of COASTal ecosystems through rivers to sea connectivity	10/2021 - 03/2026	https://rest-coast.eu/
RESTORE 4Cs	Modelling RESTORation of wEtlands for Carbon pathways, Climate Change mitigation and adaptation, ecosystem services, and biodiversity, Co-benefits	01/2023 - 12/2025	in progress
REWET	REstoration of WETlands to minimise emissions and maximise carbon uptake – a strategy for long term climate mitigation	10/2022 - 09/2026	in progress
REXUS	Managing Resilient Nexus Systems Through Participatory Systems Dynamics Modelling	05/2021 - 04/2024	https://www.rexus project.eu/
WATERLANDS	Water-based solutions for carbon storage, people and wilderness	12/2021 - 11/2026	https://waterlands.eu/
WET HORIZONS	Upgrading knowledge and solutions to fast-track wetland restoration across Europe	09/2022-08/2026	https://www.wet horizons.eu/

Riverine and coastal wetlands are vital ecosystems for nature and people. They provide significant contributions to human health and well-being, biodiversity conservation, climate change mitigation and adaptation. To halt the decline of wetland ecosystems in Europe and to boost their resilience, there is an urgent need to scale up action. This paper discusses barriers and presents recommendations for the effective restoration of riverine and coastal wetlands in Europe, highlighting the importance of integrating initiatives across science, policy and practice.

DOI 10.19217/hgr233en

Federal Agency for
Nature Conservation