PATHWAYS TO ECOLOGICAL RESTORATION IN THE UNESCO BIOSPHERE RESERVE ELBE RIVER LANDSCAPE

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Abstract

River restoration has emerged as a response to human modification of rivers, aiming to re-establish longitudinal and lateral connectivity, restore morphological dynamics, and recover ecosystem functions such as habitat provision, nutrient cycling, and flood regulation. This article examines the implementation or river restoration projects in the Elbe River Landscape Biosphere Reserve (Germany). Results show that large-scale restoration is enabled by sustained funding, NGO engagement, and integrative governance, particularly through synergies between flood protection and floodplain restoration. However, structural constraints persist due to competing waterway management objectives and land-use conflicts. While restoration improves local ecological conditions and supports climate adaptation and mitigation, its spatial scale remains insufficient to counteract global biodiversity decline, underscoring the need for broader policy integration and systemic change.

Keywords: Anthropocene; UNESCO biosphere reserve, river restoration; biodiversity; nature-based solution

1. Introduction: Human modifications to the Elbe River

Rivers such as the Elbe naturally migrate across their floodplains and thereby continuously reshape surrounding landscapes. Channel migration occurs through lateral erosion, and when meander bends are naturally cut off, they form isolated water bodies known as oxbow lakes (Wetzel, 2001). Flood events play a particularly important role in this morphodynamic system, as increased discharge and inundated areas intensify erosional processes (Baynes et al., 2015). The resulting rise in sediment transport leads to enhanced deposition in zones of reduced flow velocity. In response to these dynamic and often hazardous conditions, riparian communities implemented a range of structural measures to protect settlements and infrastructure. Along the Elbe, earthen levees were constructed from the 12th century onwards (Faulhaber, 2013) and meander cutoffs were later introduced to stabilize the channel and distance the river from populated areas (Scholten et al., 2003).

State-led policies drove extensive river modification especially during the 19th and 20th centuries. In contrast to arid regions, where river modification often primarily served irrigation, interventions in northern Germany focused on flood protection, wetland drainage for agricultural conversion and navigation. Since the 18th century, floodplains have been systematically drained to expand agriculture (Scholten et al., 2003). From the 1960s, the socialist German Democratic Republic implemented large-scale "melioration" programmes to intensify agricultural production through wetland drainage, significantly affecting the Elbe floodplain (Quast, 1999). This was enabled by inexpensive lignite-based electricity powering extensive pumping systems used to dewater and cultivate former wetlands.

A key consequence of these engineering interventions is the loss of floodplain ecosystems and associated habitats, leading to substantial biodiversity decline. Levee construction has largely prevented overbank flooding of the morphological floodplain, while bank stabilization has confined erosion to the channel and reduced lateral dynamics. Although these measures have effectively protected human assets, they have also diminished the river's capacity to create and sustain habitat diversity. Confinement of the active floodplain between levees further increases vulnerability to levee failure during extreme flood events. This condition highlights a clear synergy between flood risk management and ecosystem restoration. The "room for the river" approach—through levee relocation and expansion of the active floodplain—can reduce levee stress and flood risk while restoring space for fluvial processes and floodplain dynamics.

2. Restoration of rivers

In the European Union, water protection policies have achieved substantial success, and water quality across large parts of the region has improved considerably over several decades as a result of environmental regulation. But recently, the recovery of European freshwater biodiversity that was observed until around 2010 "has come to a halt" (Haase et al., 2023).

Although some decades of experience are available now, the restoration of rivers is a relatively recent phenomenon. River morphology, natural dynamics and habitat diversity all constitute river restoration today, but were not initially at the center of water policy. Water policy initially focused on water quality and regulated the discharge of pollutants and wastewater treatment. These changes were effective, notably with broadscale legislation on wastewater treatment resulting in reduction of organic pollution in many European rivers until the 1990s (van Dijk et al., 1994).

Connectivity along river systems and between rivers and their floodplains is central to contemporary river restoration concepts (Haase et al., 2025). Intact river–floodplain ecosystems deliver a wide range of ecosystem services, including habitat provision, nutrient cycling, and soil formation (Petsch et al., 2023). Active floodplain forests buffer hydrological extremes by temporarily storing floodwaters and gradually releasing them during drought periods, thereby attenuating hydrological variability and supporting climate change adaptation (Petsch et al., 2023; Schindler et al., 2014). Flood events also transport fine organic and inorganic sediments onto floodplains, enhancing soil carbon stocks and nutrient availability. These processes promote higher primary productivity and enable active floodplain forests to sequester more carbon than hydrologically disconnected systems (Biwer & Kleinwächter, 2025), highlighting the dual role of river restoration in both climate change adaptation and mitigation.

Longitudinal connectivity maintains natural flow regimes, facilitates ecological corridors for species migration and dispersal, and sustains sediment transport processes that underpin riverine landscape dynamics (Baynes et al., 2015; Palmer et al., 2014). River restoration seeks to reverse anthropogenic alterations such as channel straightening, bank reinforcement, floodplain drainage and intensive land use, and dam construction (Wohl et al., 2015). Common measures include the restoration of longitudinal connectivity through barrier removal or fish passage structures; reconnection of rivers and floodplains via removal of bank reinforcements; morphological rehabilitation through re-meandering and reconnection of cut-off channels; floodplain expansion via relocation of levees; habitat enhancement through re-establishment of floodplain forests, species-rich grasslands, and other native vegetation types; and the addition of structural elements such as large wood or boulders. Recently, policy initiatives have further accelerated implementation. In the European Union, the Nature Restoration Regulation adopted in 2024 places strong emphasis on river restoration, including the target of restoring 25,000 km of rivers to a free-flowing state by 2030 (Stoffers et al., 2024).

3. A biosphere reserve and a new landscape narrative for Elbe River: Naturalness of the river as heritage

The Elbe River Biosphere Reserve, established in 1979 and progressively expanded to encompass approximately 400 km of river corridor and sections of major tributaries, represents a long-term effort to conserve riparian habitats, most notably floodplain forests. As part of the UNESCO Man and the Biosphere (MAB) Programme, biosphere reserves were originally conceived in the 1970s as experimental sites for addressing ecological crises through scientific research. Since the 1990s, the programme has increasingly emphasized applied sustainable development, integrating biodiversity conservation with socially and economically compatible land use through local participation. Today, more than 800 biosphere reserves exist worldwide, often rebranded as "biosphere regions" or "biosphere parks" to avoid restrictive connotations associated with the term "reserve." The Elbe Biosphere Reserve constitutes an administrative mosaic spanning five German federal states, each with its own governance structure, yet unified by the shared vision of framing the Elbe's comparatively high degree of naturalness—relative to other major German rivers—as a valuable natural heritage. This vision seeks to reconcile ecological integrity, economic development, and social equity. River restoration and education form a core component of the Biosphere reserve's activities, coordinating and implementing restoration projects, emphasizing the distinction between natural and human-altered river dynamics, identifying avoidable impacts, and promoting learning-based, participatory approaches to sustainable river landscape management.

4. River restoration in Biosphere Reserve Elbe River Landscape

Together with nature conservation NGOs, the Biosphere Reserve initiated its first large-scale river restoration projects in the late 1990s, with implementation accelerating throughout the 2000s and continuing to the present. Most projects are implemented by NGOs using public funding, often in close cooperation with the Biosphere Reserve administration through dedicated river restoration units. Planning is typically highly complex and involves hydrodynamic modelling, stakeholder participation processes, regulatory approval under water law, and land acquisition, with restored areas subsequently transferred to conservation NGOs or public ownership.

Figure 1: Dike relocation near Lenzen with 420 hectares of restored floodplain landscape, demonstrating the outstanding importance of reactivating natural floodplains as an important component of preventive flood protection. (Photo: Jen Guyton/BUND)

4.1 Preconditions for effective river restoration: Funding and integrative governance

In addition to completed projects, further river restoration initiatives are currently in planning. These projects typically pursue two main objectives: (i) the reclamation of active floodplain areas through relocation of flood protection dykes, and (ii) the ecological enhancement of floodplain habitats through measures such as floodplain forest re-establishment and reconnection of former river channels. In the following subsections, we examine enabling and limiting factors influencing the effectiveness of river restoration.

Within the Biosphere Reserve Elbe River Landscape, government funding programmes have provided relatively continuous financial support for river restoration over approximately two decades. This has enabled nature conservation NGOs to establish specialised offices with dedicated expertise in river restoration. On large regulated rivers, where navigation and flood protection are major concerns, restoration projects are highly complex, and institutional experience accumulated through sustained project implementation is a key success factor. A further enabling condition is the reduction of governance fragmentation (Aschenbrand & Michler, 2021). Multiple organisations and administrative levels hold decision-making authority relevant to river and floodplain restoration. In the case of the Elbe, the federal waterway authority is responsible for navigation infrastructure and owns the river as a federal waterway, whereas sub-national authorities are responsible for flood protection and dyke maintenance (Aschenbrand, 2022). Effective restoration is therefore only possible through close inter-institutional coordination.

The following sections address (i) the synergy between river restoration and flood protection as a key enabling factor and (ii) the role of waterway designation as a structural constraint. The latter reflects a long-standing management paradigm that frames the Elbe primarily as a navigation corridor.

4.2 Enabling synergies between river restoration and flood protection

In heavily modified river landscapes such as the Elbe, where agriculture and settlements occupy much of the former active floodplain, floodplain restoration and flood protection are inherently interlinked. Dyke relocation increases floodplain storage capacity, allowing floodwaters to spread over larger areas, thereby reducing peak water levels and relieving pressure on flood protection infrastructure. Consequently, nature conservation and flood risk management objectives can be achieved through shared interventions. However, this synergy also involves trade-offs. Floodplain restoration aims not only to increase floodplain area but also to re-establish functional habitats, particularly floodplain forests in the Elbe context. Forest development within the active floodplain may slightly increase hydraulic roughness and potentially raise upstream water levels during extreme events. Floodplain forests are therefore often considered by water management authorities as flow obstructions that could affect dyke stability under extreme flood conditions (Thiele et al., 2023). As a result, hydrodynamic impacts must be rigorously modelled, and regulatory approval often requires demonstration of “flood neutrality,” which can constrain restoration feasibility at larger scales. This tension is typically resolved through integrated dyke relocation and floodplain restoration under the principle of “more room for the river.” The dyke relocation project near Lenzen exemplifies this approach, where approximately 420 hectares of floodplain were reactivated, demonstrating the effectiveness of floodplain restoration as a component of preventive flood protection (Alexy, 2013). Such projects illustrate that nature conservation, flood protection, and, in some cases, agriculture can be reconciled through integrated planning (Damm, 2013), underscoring the role of biosphere reserves as model regions for sustainable development.

4.3 Structural constraints on restoration - The Elbe as a federal waterway

The Elbe is designated as a federal waterway, placing it under the jurisdiction of the Federal Waterways and Shipping Administration, which is responsible for its maintenance and development. Although the Elbe is of limited importance for freight transport due to frequent low water levels and the availability of alternative canal routes (Gohlisch et al., 2005), maintenance obligations persist to ensure navigability. This institutional mandate creates a structural conflict between navigation-oriented river engineering and floodplain restoration. A key element of this conflict is the use of groynes, which are transverse hydraulic structures designed to concentrate flow in the central navigation channel and maintain sufficient water depth during low-flow conditions. Prior to their widespread construction in the 19th century, the Elbe exhibited a highly dynamic morphology with shifting widths, depths, and sedimentary features such as sandbars formed during floods (Faulhaber, 2013), which limited navigability.

Today, the river is regulated by more than 6,900 groynes and approximately 300 km of bank revetments (Kleinwächter et al., 2017). While groyne fields promote local sediment deposition and habitat heterogeneity, long-term infilling reduces morphological dynamics and leads to habitat loss for aquatic species. Alternative groyne designs attempt to reconcile bank protection and flow regulation with partial ecological functionality, but trade-offs remain. To address these conflicts, the "Gesamtkonzept Elbe" (General Elbe Concept) was developed as an integrated planning framework. It seeks to reconcile navigation requirements with ecological restoration, flood protection, and biodiversity conservation (Bundesministerium für Digitales und Verkehr, 2024). It promotes coordinated maintenance strategies aimed at improving ecological status while maintaining functional navigation infrastructure (Kleinwächter et al., 2017). While this integrative approach is promising, its ecological effectiveness remains to be fully demonstrated in practice.

5. Discussion and Conclusion

River restoration has been shown to enhance habitat diversity and species richness (Hering et al., 2015) and to contribute to both climate change mitigation and adaptation (Biwer & Kleinwächter, 2025). However, its effectiveness remains constrained by multiple interacting limitations, and it has not yet reversed global trends in freshwater biodiversity loss. At broader spatial scales, restoration efforts remain limited in extent relative to the magnitude of biodiversity pressures. Haase et al. (2025) report generally poor outcomes of conservation interventions aimed at halting freshwater biodiversity decline. Full restoration of morphological floodplains is rarely feasible in large river basins due to land availability constraints and the need for extensive negotiation processes. As emphasized by Wohl et al. (2015), river restoration is fundamentally a social process requiring holistic ecosystem understanding.

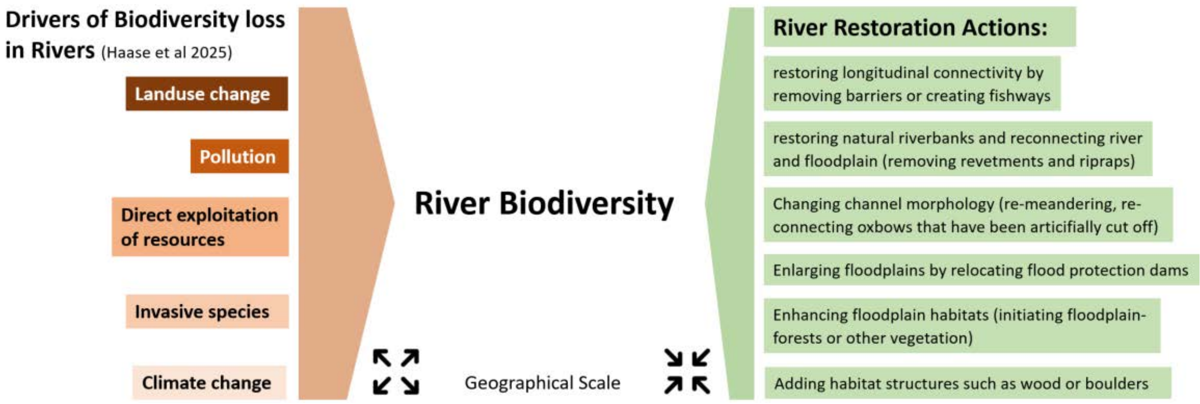

Figure 2: River Biodiversity llustration based on and expanded from Haase et al. (2025)

Many drivers of biodiversity loss—including land-use change, pollution, resource exploitation, invasive species, and climate change—operate at spatial and temporal scales beyond the reach of local restoration measures. Consequently, while restoration can effectively improve ecological conditions locally, it must be complemented by broad-scale policy interventions (Haase et al., 2023). In this context, emerging regulatory frameworks such as the EU Nature Restoration Regulation aim to scale up implementation, although uncertainties remain regarding definitions such as "free-flowing" rivers and potential risks to relatively intact systems (Stoffers et al., 2024). Beyond spatial constraints, restoration is also limited by functional and institutional constraints. Conflicts over intervention intensity often arise from competing land-use interests and sectoral governance fragmentation (Wohl et al., 2015), including tensions between navigation, flood protection, and conservation authorities. As long as the Elbe retains its designation as a federal waterway, navigation objectives remain legally prioritized, limiting the scope for morphological restoration.

From an ecosystem services perspective, the Elbe is predominantly managed for navigation, while other ecosystem services are undervalued (Petsch et al., 2023; Sousa et al., 2025). This is particularly notable given the declining economic relevance of inland shipping on the river (Gohlisch et al., 2005), a trend expected to accelerate under climate change due to increased hydrological variability affecting navigability. These developments suggest a need to reassess the valuation of river ecosystem services, particularly in relation to flood and drought regulation and carbon sequestration. However, institutional prioritization of navigation remains legally entrenched. Alternative governance concepts, including the recognition of "rights of rivers" as implemented in countries such as Australia, India, and New Zealand, offer potential conceptual inspiration (O'Donnell & Talbot-Jones, 2018), despite their unconventional legal framing.

In conclusion, the Biosphere Reserve demonstrates how integrated governance, long-term funding, and NGO collaboration can effectively advance river restoration as a multifunctional strategy. River restoration has proven effective not only for biodiversity conservation (Damm, 2013; Hering et al., 2015) but also as a nature-based solution for flood protection (Alexy, 2013) and climate adaptation (Biwer & Kleinwächter, 2025). Its success is highest where synergies between policy goals are actively exploited and institutional integration is strong. Conversely, limited intersectoral coordination constrains effectiveness. UNESCO Biosphere Reserves can function as bridging organisations (Olsson et al., 2007), facilitating such integration, but require sustained political support to fully realize this potential.

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