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Floodplain Conservation Versus Landscape Development—How to Tackle the Multifunctional Management Issue

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ABSTRACT

Ecosystems lining rivers perform a number of functions making it reasonable to protect them from significant degradation. A natural characteristic of floodplains is their regular inundation, during which sediments, wood and nutrients are eroded, mobilized or deposited, thereby restoring these valuable ecosystems. However, the key attributes of floodplains, such as fertile soil, flat terrain, availability of water, sediments and wood, are also the subjects of human exploitation. The flood control embankments in urban and agricultural areas are justified and effective solutions to reduce flood risk. However, when combined with unnaturally incised and enlarged river channels, they are limiting natural flooding and connectivity of floodplains is fundamentally degraded. To analyze different approaches to floodplain protection, we conducted a review supported by the expertise of specialists in selected countries of Central and Southern Europe. We concluded that in most of these countries, there is no targeted protection of floodplains as an ecological phenomenon. Comprehensive protection is mostly only afforded to small-scale areas, valued due to the occurrence of Europe's most threatened species and habitats (Natura 2000 network). Except for segments of a few large rivers, these sites are not connected and therefore significant support for the longitudinal continuity of water-dependent ecosystems cannot be expected. This inevitably leads to the gradual degradation of floodplain ecosystem functions and services. The floodplain management in non-urban areas, wherever natural spillover of floods to the surroundings is possible and where floodplains have been inappropriately embanked, seems to be a suitable solution for supporting the ecological functionality of these ecosystems.

This article is categorized under:
Water and Life > Stresses and Pressures on Ecosystems
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1 | Introduction

Riparian zones, floodplains, and river-marginal wetlands are key landscapes of strategic importance to human society (Acreman et al. 2007; Mitsch and Gosselink 2000; Thoms 2003; Tockner and Stanford 2002). These unique systems are characterized by recurrent floods, which classify rivers as disturbance-driven systems undergoing periodic habitat rejuvenation. This process creates dynamic mosaics of habitats at varying successional stages, distinguished by differences in complexity, connectivity, spatial heterogeneity (Thorp et al. 2006), while individual habitats vary in moisture levels, sediment properties, productivity, and biotic diversity (Geilen et al. 2004). Therefore, floodplains and their integral parts (such as riparian zones and wetlands) are widely acknowledged as ecosystems of remarkably high biodiversity (Ward and Tockner 2001). Floodplain areas also provide numerous ecosystem services (Schindler et al. 2016; Riis et al. 2020 or, Petsch et al. 2023), including local climate regulation, nutrient cycling, floodwater retention, groundwater level recharge and stabilization for drinking water abstraction, carbon sequestration (Salerno et al. 2023), and recreational opportunities in an urban environment (Hoehn et al. 2003; Millennium Ecosystem Assessment 2005; TEEB 2010). These attributes make floodplains vital ecosystems that, especially in lowland landscapes, function as hotspots of biodiversity, and ecosystem services (Schindler et al. 2016; Tomscha et al. 2017).

However, human activities exert significant pressure on floodplains, leading to their transformation and degradation (Peipoch et al. 2015; Tockner and Stanford 2002). River regulation measures, including channelization, dam construction, and levee building for flood control, have drastically reduced the extent and spatiotemporal complexity of floodplains (Erős et al. 2019). These interventions have led to the dramatic loss of aquatic and riparian species as well as essential ecosystem services (Tockner and Stanford 2002). River floodplains are among the most threatened ecosystems globally, making their protection and restoration a critical priority for river managers (Weigelhofer et al. 2020; Perry et al. 2024). Alarmingly, up to 90% of former European floodplains have been degraded to a state of functional extinction, while approximately 95% of natural riverine wetlands have been lost (Tockner et al. 2010; Tockner and Stanford 2002). As a result, active floodplains in Europe have become particularly rare (Schindler et al. 2016; Perosa et al. 2021; Natho and Hudson 2024; Stammel et al. 2025), underscoring the urgent need for their conservation. Beyond preserving intact floodplain rivers as strategic global resources, it is equally critical to restore hydrologic dynamics, exchange of matter (sediments and organic material), energy, and biota among riverine landscape elements, and to support riparian vegetation in rivers that still have some degree of ecological integrity.

In the European countries, major directives exist, which set conservation and/or restoration aims for aquatic ecosystems and provide a guideline for decision processes in floodplain restoration projects (Gumiero et al. 2013; Hein et al. 2019; Moss 2007). Furthermore, national legislation dedicated to floodplain protection has been established in several European countries. However, the long-term effectiveness of protection measures varies, and human pressures continue to escalate (Jones et al. 2018; Schleicher et al. 2019). For instance, in many European countries, efforts to conserve biodiversity rely on the "Natura 2000 ecological network of protected areas"; however, the resulting impact and efficacy of this network remain subjects of intense debate (Davis et al. 2014; Friedrichs et al. 2018; Hermoso et al. 2018; Popescu et al. 2014). Furthermore, urban expansion encroaches upon these protected areas, underscoring the urgent need for stricter legal protections and enhanced law enforcement measures (Concepción 2021).

The primary aim of this article is to compare floodplain protection implementation across selected European countries: Czechia, Germany, Italy, Slovakia, Slovenia, Spain, Switzerland, Croatia, and Austria. This selection includes Central and Southern European countries, having comparable population density yet differing in natural characteristics—such as watershed gradient, parent material, elevation, and climate. These factors influence historical settlement patterns and land use within floodplains, leading to varying national needs and approaches to floodplain protection. This review was conducted by national experts through an in-depth analysis of publicly available legislation and strategic documents related to floodplain protection, supplemented by their own knowledge and interpretation of available information. All co-authors of this paper, experts in floodplain management, hydrology, and related fields, contributed by describing floodplain protection in their respective countries. The existence and character of valid legislation for floodplain protection were then discussed, along with the main factors contributing to floodplain degradation in each country. The analysis was further supplemented with findings from scientific literature describing floodplain protection practices in additional European countries, such as the Netherlands, Hungary, Ireland, Ukraine, or Great Britain. The study examines administrative frameworks and land governance systems, highlighting differences in approaches and implementation effectiveness among the selected countries. Particular attention is given to EU directives, national floodplain protection laws, and the key challenges associated with their implementation across Europe.

2 | Floodplain Conservation Versus Landscape Development in European Countries

2.1 | Current Threats to European Floodplains

Floodplains in Europe are increasingly threatened by ongoing modification and degradation driven by agriculture, forestry, industry, urbanization, and water management, including navigation and large hydropower development (Arthington et al. 2010; Sommerwerk et al. 2010; Monk et al. 2019). Alterations such as channelization, changes in hydrological regime, wetland drainage, flood protection structures (e.g., levees and embankments) and intensive forestry practices have led to widespread degradation of riverine wetlands (Hesselink 2002; Henry et al. 2002; Hey and Philippi 1995; Laudon et al. 2011; Rinaldi et al. 2013). Many floodplains are now hydrologically disconnected from river channels (referred to as former floodplains), resulting in reduced habitat heterogeneity, accelerated terrestrialization, and biodiversity loss (Amoros and Bornette 2002; Stanford et al. 2005). Even remaining active floodplains face threats from human activities such as infrastructure development, urbanization, and intensive agriculture. These changes compromise the ecological integrity and functioning of floodplain ecosystems (Hale and Adams 2007; Weigelhofer et al. 2011).

Chemical contamination from fertilizers, industrial activities, urban wastewater, pesticides, and heavy metals poses a significant threat to European rivers, profoundly impacting biodiversity (Schiemer 1999; Schindler et al. 2016). River-floodplain ecosystems are often affected by multiple stressors simultaneously, leading to complex responses, including both antagonistic and synergistic effects (Tockner et al. 2010; Monk et al. 2019). Alterations in the hydrological regime (e.g., due to reduced flows) can lead to increased pollutant concentrations and changes in temperature regimes (Tockner et al. 2010), which may further enhance the spread of invasive species (Cowell and Dyer 2002). These impacts can be compounded by river channelization and climate change. According to the first Working Group contribution to the IPCC's Sixth Assessment Report (IPCC 2021), extreme weather events, such as prolonged droughts and severe floods, are expected to become more frequent, with both effects further aggravated by negative anthropogenic modifications to river ecosystems.

Understanding the complex interactions of multiple stressors in spatially and temporally dynamic floodplain systems remains a significant challenge for ecologists, highlighting the need for effective management strategies to mitigate their adverse impacts (Dafforn et al. 2016). Despite ongoing efforts to preserve and restore the natural functions of floodplains, anthropogenic activities persist in degrading floodplain conditions, primarily through land cover changes that alter the spatial and ecological structure of these areas. Land cover changes refer to the systematic transitions between different land cover categories over a specified period, capturing processes such as urbanization, afforestation, deforestation, agricultural change, and wetland modification, as derived from spatial monitoring datasets. Figure 1 illustrates land cover changes for selected European countries between 2000 and 2018 based on data from the European Environment Agency (EEA 2020).

2.2 | Floodplain Protection in Selected European Countries

2.2.1 | European Directives

Floodplain conservation in the European Union is governed by a suite of interrelated directives and strategies that reflect evolving priorities in environmental policy, water management, and biodiversity conservation. Historically, catastrophic floods in the early 2000s (Bronstert 2003) catalyzed a shift in European water policy toward integrated and adaptive flood risk management which led to the adoption of key legal instruments to enhance ecological status, reduce flood risk, and conserve habitats. These major directives, which play a significant role in shaping the management of rivers and floodplains (Hornung et al. 2019), include the EU Water Framework Directive (WFD), the EU Floods Directive (FD), and the EU Habitats Directive (HD) (EEA 2016; Tockner et al. 2010).

2.2.1.1 | Water Framework Directive (WFD, 2000/60/EC). The Water Framework Directive (WFD) provides a foundation for integrated water resources management. Its primary objective is to enhance the ecological status of aquatic ecosystems by promoting measures aimed at reducing human pressures on these systems (Grizzetti et al. 2016; Jähnig et al. 2009) and requires member states to restore or maintain the good ecological condition of river systems (Council of the European Communities 2000).

The WFD implements comprehensive, basin-scale monitoring and assessment programs based on a multi-species, ecosystem-based approach (Serra-Llobet, Tourment, et al. 2022) and emphasizes the restoration of natural hydro-geomorphic dynamics (Weigelhofer et al. 2020). While it highlights the structural integrity of riparian zones as essential for achieving good ecological status (Meyerhoff and Dehnhardt 2007; Gumiero et al. 2013), no specific organisms or habitats are addressed in WFD, thus it does not explicitly include riparian ecosystems as a quality element (EC 2000). This omission has contributed to their continued degradation despite two River Basin Management Plan cycles (González del Tánago et al. 2021; Urbanič et al. 2022). Additionally, a temporal disconnect between the directive and recent scientific advances in riparian vegetation dynamics and bio-geomorphic modeling may further hinder their effective representation in hydromorphological assessments (González del Tánago et al. 2021). This disconnect stems from the fact that the Water Framework Directive (2000/60/EC) predates key developments in the understanding of riparian vegetation dynamism and bio-geomorphic processes, resulting in assessment frameworks that do not fully reflect contemporary scientific knowledge. Consequently, current hydromorphological evaluation practices may overlook critical interactions between vegetation cover and geomorphological characteristics that recent research has demonstrated to be essential for accurately characterizing river system functioning.

2.2.1.2 | Floods Directive (FD, 2007/60/EC). The Floods Directive (FD) focuses on reducing flood risks to human welfare, which often creates trade-offs with the WFD (EEA 2016). The primary aim of the FD is to minimize the adverse impacts of flooding on human health, economic activities, the environment, and cultural heritage (EC 2007). The FD lacks specific measures to protect or restore riparian zones and floodplains as a flood mitigation strategy. However, measures implemented under the FD must align with the objectives of the WFD to ensure consistency between the two directives (EEA 2016; Evers and Nyberg 2013) and cost-benefit analysis must be carried out in the selection of measures.

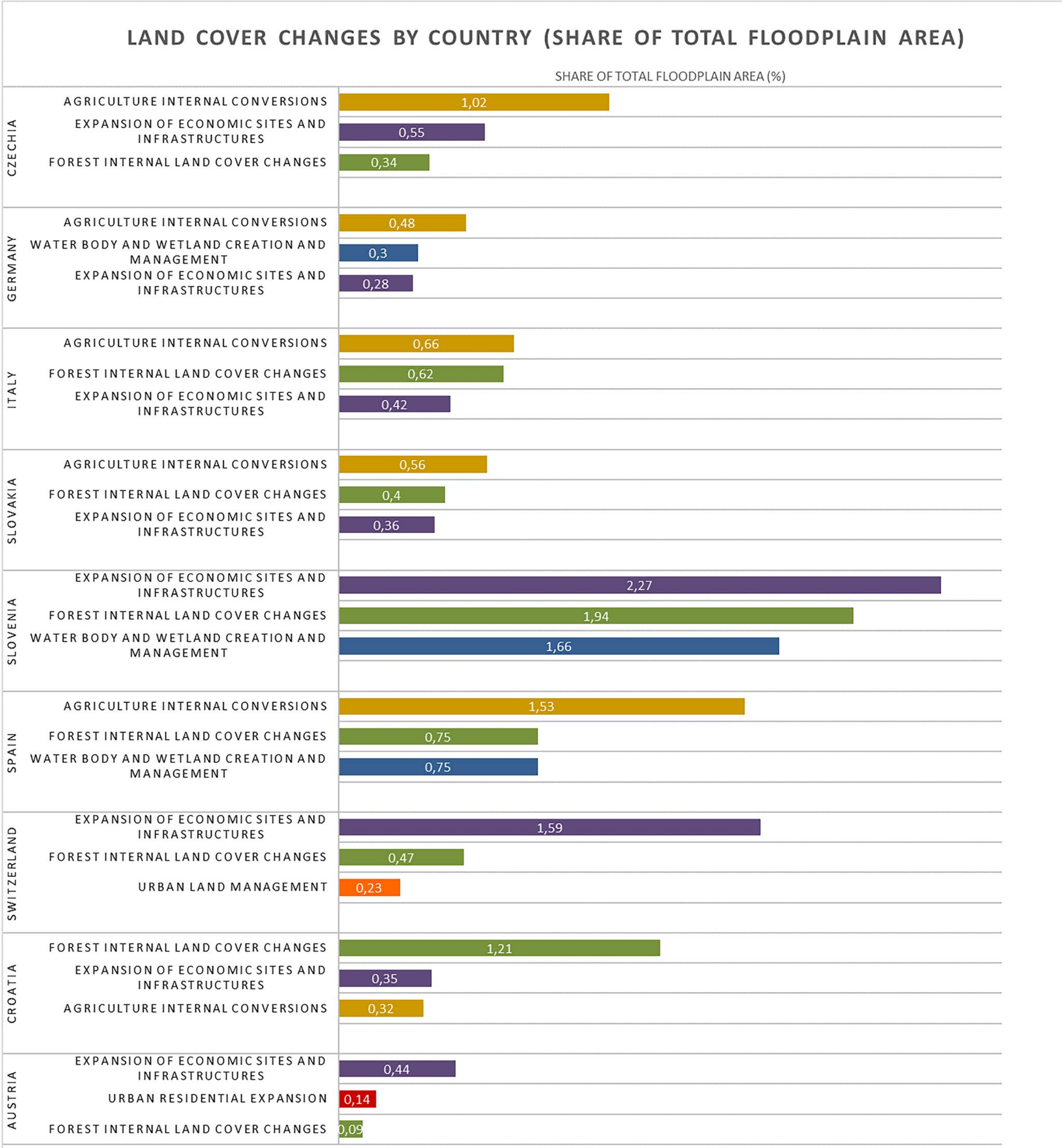

FIGURE 1 | The three most significant land cover changes from 2000 to 2018 in floodplains of the selected European countries (data: EEA 2020). For example, in Czechia, agriculture internal conversion represents the most significant land use change in floodplains, which accounts for 1.02% of the total floodplain area in the country. More precise explanation of land cover changes: (1) Land use conversions, such as the transformation of grasslands into fields; (2) Occupation of land by new industrial areas and infrastructures; (3) Forest management, such as timber harvesting and changes in species composition; (4) Management of water bodies, such as the construction of reservoirs, ponds, and wetland areas; (5) Changes in the urban environment, such as the conversion of green spaces into built-up areas.

2.2.1.3 | Habitats Directive (HD, 92/43/EEC). The EU Habitats Directive (HD) is founded on two main pillars: the Natura 2000 network of protected sites and a strict regime of species protection (EU 2011). Its primary objective is to conserve rare, threatened, or endemic species of flora and fauna, as well as habitats located within designated Natura 2000 areas, in line with the European Commission's biodiversity strategy (Council of the European Communities 1992; Gumiero et al. 2013). However, this approach is largely focused on individual habitats or species (Weigelhofer et al. 2020), which proves less effective when aiming to protect complex floodplain systems that depend on dynamic ecological and geomorphological processes.

Importantly, the HD was not originally intended to address issues related to floodplain integrity. Consequently, floodplain habitats that fall outside the Natura 2000 network remain unprotected (Broekmeyer et al. 2017), which is a problem particularly in regions with intensive agriculture or urbanization, where there is a need for enhanced riparian zone management, including the restoration of degraded zones (Urbanič et al. 2022).

2.2.1.4 | Other European Policies Contributing to Floodplain Protection. In addition, the EU's Common Agricultural Policy (CAP) and the EU Landscape Convention (Council of Europe 2000) have significantly influenced the management of rivers and floodplains (Hauck et al. 2014; Seardo 2015). The European Commission has also introduced its 2030 Biodiversity Strategy (EC 2020), a component of the European Green Deal. This strategy aims to make Europe climate-neutral by 2050, transitioning to a clean, circular economy while simultaneously restoring biodiversity and reducing pollution. Key targets include expanding protected areas to cover at least 30% of Europe's land and seas and restoring at least 25,000 km of rivers (Serra-Llobet, Jähnig, et al. 2022). Unfortunately, restoring 25,000 km of rivers is the only quantitative target related to floodplains that is specified by the Nature Restoration Law (Frantzeskaki and Malamis 2024).

2.2.2 | National Floodplain Protection Laws, Floodplain Delineation and Main Human Pressures

While European directives provide a common framework, several European countries have also implemented national legislation to support floodplain protection and management. This section presents a comparative analysis of national legislative approaches to floodplain protection in a selection of European countries.

To gather the necessary information, all co-authors (recognized experts in floodplain management, hydrology, and related disciplines) completed a structured questionnaire. Their responses were informed by both professional expertise and a review of publicly available strategic documents related to national floodplain policies.

The questionnaire focused on key aspects of floodplain protection, including the existence and characteristics of national policies, the availability and attributes of official floodplain maps (e.g., scale, geographic coverage, criteria for inclusion), and the delineation methods and objectives. It also examined whether both active and inactive (former) floodplains are accounted for in national strategies. The final section explored expert assessments of the effectiveness of national and EU-level floodplain protection measures, along with the principal threats and anthropogenic pressures influencing the ecological integrity of floodplains in each country.

2.3 | Major Challenges in Floodplain Conservation

2.3.1 | Current Practices and Effectiveness of Floodplain Conservation

Although major directives address the protection and restoration of aquatic ecosystems, current river restoration frameworks remain largely aquatic-centric, prioritizing in-stream conditions while undervaluing floodplains, and their land-water linkages (Schulz et al. 2024; Bolland et al. 2012). As a result, key aspects such as floodplain productivity, nutrient dynamics, and hydrological and sediment connectivity have received comparatively limited attention (Junk 2005), despite floodplains being among the most diverse yet imperiled freshwater habitats (Bolland et al. 2012). This narrow focus also leads to neglect of cross-boundary ecological processes, such as energy and nutrient fluxes via insect emergence, that integrate aquatic and terrestrial systems (Schulz et al. 2024). While energy inputs mediated by riparian shading and nutrient transport via terrestrial advection often dominate ecosystem-scale fluxes, emergent aquatic insects can nonetheless represent a non-trivial pathway for transferring high-quality biomass and essential fatty acids to riparian consumers, particularly in systems where terrestrial subsidies are constrained or spatially heterogeneous (Ohler et al. 2024; Rideout et al. 2025). Overcoming these limitations requires a meta-ecosystem perspective that explicitly treats rivers and floodplains as interconnected components of landscape-scale ecological functioning (Frantzeskaki and Malamis 2024; Stoffers et al. 2024).

Adopting an integrated, landscape-scale perspective is essential for understanding the effectiveness of floodplain protection under climate change, because floodplain processes and biodiversity outcomes depend on spatial connections across the wider river–floodplain system. The meta-ecosystem approach provides such a framework by highlighting the multiple benefits of hydrologically reconnecting floodplains, including enhanced biodiversity, natural flood attenuation, improved water quality, and other ecosystem services (Serra-Llobet, Tourment, et al. 2022)—benefits that are increasingly critical in the context of accelerating global change (Tockner et al. 2010). Although EU directives offer the primary policy framework for floodplain conservation, their practical impact remains uneven and often insufficient (Friedrichs et al. 2018; Hermoso et al. 2018). This has heightened the importance of the recently adopted Nature Restoration Regulation (EU) 2024/1991, which explicitly promotes a holistic, cross-ecosystem perspective aligned with meta-ecosystem principles.

National nature protection laws also contribute to floodplain management, though only a few countries, such as Czechia and Switzerland, have specific national protections aimed at floodplains. In Czechia, for instance, protection laws apply broadly to all floodplains. However, such comprehensive legislation often conflicts with existing land use, particularly in areas containing buildings or old industrial sites established before floodplain protection laws were enacted. This conflict complicates floodplain conservation efforts, as many intensively used floodplain areas continue to experience development or shifts toward ecologically unsustainable practices even after legal protections are introduced. A critical challenge lies in assessing whether these floodplain sections retain ecosystem functions after previous human interventions or whether they hold restoration potential that justifies imposing restrictions on further development (Jakubínský et al. 2021). In Czechia, as in many other countries, new development in floodplains is partially regulated due to their flood-prone nature (as shown in Table 1). However, these regulations typically restrict only certain activities, such as the construction of residential or industrial buildings, while other harmful interventions remain largely unregulated (particularly agricultural use leads to soil sealing and soil infiltration capacity reducing). Floodplain ecosystems are fundamentally dependent on periodic inundation, sediment transport, and the dynamics of riparian vegetation—processes that are frequently disrupted by historical land-use modifications and alterations to hydrological and sediment regimes. As a result, the overall effectiveness of floodplain protection laws is often limited, even when such laws are in place.

Floodplain restoration in Europe often faces significant trade-offs with socio-economic development, as efforts to reclaim inundation areas clash with urban expansion, agriculture, and infrastructure interests. Historical conversion of floodplains for farming and settlements has greatly reduced flood storage and habitat (Ebert et al. 2009). Restoring these areas can enhance flood mitigation and biodiversity, but it frequently conflicts with existing land uses and plans (Scholten et al. 2005). Rapid urbanization on floodplains has heightened flood exposure (EEA 2017), prompting policies like the Netherlands' Room for the River programme that prohibit new housing in flood zones to safeguard space for river expansion (Havinga 2020).

Agriculture is a common source of tension: for example, along the Middle Elbe in Germany, extensive floodplain forests were cleared for large-scale cultivation, and recent projects to set back dikes and re-wet these areas have met with landowner resistance due to the loss of fertile land (Scholten et al. 2005). Conflicts also arise with infrastructure: a major Rhône River restoration in France required lowering existing flood dikes, a move opposed by the hydropower company operating them and met with local fears of induced flooding without compensation (Guerrin 2014). Along the lower Danube, efforts to reopen former polders to flooding must weigh short-term agricultural losses against long-term gains in natural flood control and water quality—A balance that has increasingly shifted toward restoration, especially after severe floods exposed the high costs of past river regulation (Ebert et al. 2009).

The combination of proliferating extreme precipitation events (García-Ayllón and Franco 2023) and widespread floodplain encroachment across southern Europe has sharply reduced the flow regulation and flood mitigation services once provided by natural floodplains (EEA 2023), thereby heightening flood risks in many urbanized regions. In Spain's Mediterranean regions, rapid and unrestrained city expansion into highly flood-prone basins–often without accounting for hydrological hazards–has generated numerous present-day flooding problems (García-Ayllón and Franco 2023). Likewise, in Italy, conversion of permeable green land into impervious urban surfaces has been linked to increased runoff volumes and higher flood peaks (Apollonio et al. 2016). A recent analysis indicates that roughly 63% of homes and businesses in Italy's Emilia-Romagna region now sit within the 100 year flood zone (Serinaldi and Kilsby 2023). Recent studies from Portugal confirm that rapid urban expansion into flood-prone areas–such as in Lisbon and Vila Nova de Gaia–has significantly increased flood risk due to inadequate land-use planning and the loss of natural floodplain regulation (Santos et al. 2023; Mourato et al. 2013). The same situation, exacerbated by more intense rainstorms driven by climate change, has set in Attica in Greece (Lasda et al. 2010). These developments emphasize the urgent need to find effective strategies for floodplain conservation while ensuring the delivery of the ecosystem services they provide to humankind.

In Switzerland, floodplain protection is primarily implemented through spatial designation, most notably via the federal floodplain inventory, and is complemented by data identifying functional deficits and corresponding restoration needs, as documented in federal reports (BAFU (Hrsg.) 2020). In this regard, Switzerland offers a relatively effective model of floodplain protection. Since 1979, Swiss authorities have completed 848 restoration projects on streams and rivers, reconnecting 307 km of formerly degraded channels. The national strategy targets roughly 4000 km of river restoration over the next 80 years (about 50 km/year) to fully re-establish lateral connectivity with floodplains (Kurth and Schirmer 2014). Legal protections apply exclusively to selected ecologically intact floodplains, and the ecological value is evaluated in national monitoring programs. Together, these measures position Switzerland as a leading example of long-term, strategic floodplain restoration and management in Europe.

Germany also provides an example of relatively successful floodplain management. Flood protection is closely integrated with floodplain management policies, which are governed by the Federal Water Act and the National Flood Protection Programme. Additionally, compliance with the EU Water Framework Directive (WFD and the EU Floods Directive is ensured) (Kang 2022). Recent amendments to federal laws in 2021 have assigned specific restoration responsibilities to the Federal Waterways and Shipping Administration, focusing on hydromorphological measures required by the WFD (Heyden and Natho 2022). In the United Kingdom (UK), floodplain management relies on a mix of regulatory, economic, and voluntary measures. These include habitat protection regulations, nitrogen fertilizer limits, agri-environment payments for wetland conservation, and voluntary agreements facilitated by organizations such as the Farming and Wildlife Advisory Group or Linking Environment and Farming (Morris et al. 2009). The UK adopts a predominantly cooperative approach, with local authorities holding primary responsibility. Inter-institutional collaboration is supported through the land-use planning system, where regional and local planning bodies play a key role (Johnson and Handmer 2003). This system emphasizes local oversight of flooding and land use, guided by central government policy but without strict compulsion (Pottier et al. 2005).

Despite growing policy support, floodplain and river restoration efforts in Europe continue to face multi-faceted barriers that are social, technical, financial, political, institutional, and economic in nature (Christopher et al. 2024; Cortina-Segarra et al. 2021). Socially, community acceptance and risk perception often lag: residents and officials may fear increased flood risk or loss of farmland, while restoration projects frequently suffer from delayed or inadequate stakeholder engagement (Flávio et al. 2017; Santoro et al. 2019). Such gaps breed conflicts (e.g., between landowners and authorities) and opposition to measures. Technically, managers note that standard risk-assessment tools are ill-suited to the complexity and uncertainty of natural systems (Santoro et al. 2019) and projects often depend on external

TABLE 1 | National floodplain protection laws, floodplain delineation, and main human pressures on floodplains in individual European countries.

Countries	National law/legislation framework to protect floodplains	Delineation of floodplains					Effectiveness of national protection (where relevant)	Effectiveness of European protection	Primary threats
		Extent	Purpose (dominant management goal)	Method	Spatial scale	Active/inactive floodplains			
Czechia	Protection of all floodplains under the Nature and Landscape Protection Act 114/92 Coll. and subsequent Ministry of Environment decrees	For "important watercourses", mostly major watercourses, but also some smaller ones	Environmental/nature protection	Based on morphological parameters (DEM), land cover data, inundation areas, phytocenological data, soil types, and geological mapping	1:25,000	Active and inactive (former) floodplains	Low: Already degraded floodplains and their limited functions serve as the justification for allowing further land use changes	Rather low, the most effective is the protection of NATURA 2000 sites (18% of these floodplains according to EEA 2020)	Urban and industrial development, intensive agriculture (Jakubínský et al. 2021)
Germany	No national-level floodplain protection.	79 (mostly large) rivers spanning 10,297 km (4.5% of the country's total area), some smaller rivers are delineated in certain federal states (e.g., Bavaria)	Nature protection, separately also water protection and flood prevention (have different delineation)	Digital land cover model, 100year flood probability data, and semi-automated DEM calculations	1:100,000	Active and inactive (former) floodplains	Not relevant	Floodplains are partly protected by NATURA 2000 (29% according to EEA 2020), implemented into the Nature Conservation Act, and the WFD, implemented into the Water Resources Act	Intensive land use, diffuse nutrient and sediment impacts, river regulation (embankments), incision (lack of lateral connectivity), and hydropower dams, as well as navigation (BMU and BfN 2021; Schneider et al. 2017; Heyden and Natho 2022; Harms et al. 2018).

(Continues)

TABLE 1 | (Continued)

Countries	National law/legislation framework to protect floodplains	Delineation of floodplains: Extent	Purpose (dominant management goal)	Method	Spatial scale	Active/inactive floodplains	Effectiveness of national protection (where relevant)	Effectiveness of European protection	Primary threats
Italy	No national-level protection.	All watercourses, including the small ones	Flood risk management, river restoration	A combination of remote sensing and field survey, often completed using photo interpretation, geomorphic analysis, DEM and hydraulic modeling	1:10,000 and 1: 25,000	Active floodplains	Not relevant	At least a part of the active floodplain is protected from human use to promote ecosystem services and reduce flood risk in identified river morphodynamic corridors (e.g., Brenna et al. 2024).	Urban and industrial development, intensive agriculture, river regulation, and natural hazard protection (Brenna et al. 2024).
Slovakia	No national-level protection.	Flood-significant watercourses, rivers with transformed/degraded floodplain, and rivers with inhabited floodplain	Flood prevention	Based on multi-temporal spatial analyses using aerial and orthophoto images, LiDAR-derived DEM, combined with field survey and Hydraulic model Q100	1:10,000 up to 1:100,000	Active, perched, inaccessible (former) floodplains	Not relevant	Rather low, only some floodplains are protected based on European directives (WFD), Natura 2000, and the National Nature Reservation (NNR) network	Urban development, a specific feature is small hydroelectric power plants installed through abandoned or artificial channels on the floodplain (Labaš et al. 2024; Jančovič and Kidová 2024).
Slovenia	No national-level protection. There is only one limitation defined by the "Decree on conditions and limitations for constructions and activities on flood risk areas" (PISRS 2020).	Both large and small rivers (though not all are completed)	Flood prevention	Hydrological-hydraulic modeling (for Q10, Q100, and Q500 events) based on accurate terrain data, following the methodology defined by the Slovenian Water Agency[a]	Variable scale (outputs can be zoomed in as they are available in vector format).	Active floodplains	Not relevant	Rather low, only partly protected by the Water Act[b] and Natura 2000	Urban development, including public and industrial buildings[c]

(Continues)

TABLE 1 | (Continued)

Countries	National law/legislation framework to protect floodplains	Delineation of floodplains: Extent	Delineation of floodplains: Purpose (dominant management goal)	Delineation of floodplains: Method	Delineation of floodplains: Spatial scale	Delineation of floodplains: Active/inactive floodplains	Effectiveness of national protection (where relevant)	Effectiveness of European protection	Primary threats
Spain	No national-level protection. Only flood regulations that control or prohibit certain types of urban development in active floodplains (Olcina et al. 2016; Perles et al. 2018).	Most medium and large rivers (not all are completed/published)	Flood prevention	Hydraulic modeling, in some regions a combination of hydraulic, hydrologic, geomorphological, and historical flood data (e.g., in Valencia)	1:50,000	Active floodplains	Not relevant	Rather low, only partly protected by the Water Act and Natura 2000	Urban (residential and tourist) developments, communication infrastructure, industrial and agricultural uses. There are also severe disturbances caused by damming on water and sediment river flows, and also by artificial levees in some rivers (Ollero 2010).
Switzerland	National ordinance to protect selected floodplains of national importance (Swiss Confederation 2017, Auenberatungsstell 2001–2008, Waters Protection Ordinance 2008)	326 floodplains of national importance, including some small streams (the selection was done according to the ecological value) (Swiss Confederation 2017)	Nature protection (Swiss Confederation 2017; Auenberatungsstelle 2001)	Based on terrain, soil, vegetation information, and river dynamics (Auenberatungsstelle 2001)	1:25,000	Active floodplains	Good, in selected floodplains, organisms, habitats, geomorphological features, and river dynamics are conserved. Only exceptions are human hazard protection or public interests of national importance. (Roulier et al. 2020)	Not applicable	Lack of hydrodynamics due to hydropower production and natural hazard protection (dams, barriers, sediment deficits, and water deficits). Also, nutrient inflow from agriculture, gravel excavation, and increasing recreational activities. Roulier et al. 2020

(Continues)

TABLE 1 | (Continued)

Countries	National law/legislation framework to protect floodplains	Delineation of floodplains: Extent	Purpose (dominant management goal)	Method	Spatial scale	Active/inactive floodplains	Effectiveness of national protection (where relevant)	Effectiveness of European protection	Primary threats
Croatia	No national-level protection.	Only for watercourses with flood risk (independent of their size)	Flood prevention	Inundated areas based on hydrological and hydraulic modeling, with scenarios for 25, 100, and 1000 year floods, using data from digital terrain models, hydrographic surveys, and hydrological and meteorological records	1:25,000	Active floodplains (except for the Danube, which has also delineated a former floodplain thanks to the EU Interreg Danube Transnational Cooperation Program)	Not relevant	Rather low, only partly protected by the Water Act and Natura 2000	Hydropower projects, sediment extraction, urban and infrastructure development, and agriculture (e.g., Bonacci and Oskoruš 2010, 2008; Tadić et al. 2014; Gilja et al. 2010; Peršić and Horvatić 2011; Ljubenkov et al. 2024; Potočki et al. 2021)
Austria	There is a national floodplain strategy (Auenstrategie Österreich 2030+)	1033 floodplain objects (source: Lazowski and Schwarz 2023)	Nature protection	Based on fieldwork, biotope mapping, aerial photographs, and map materials, including flood lines. Flood risk areas are mapped separately using hydrological models.	1:10,000 to 1: 25,000	Not explicitly divided into active and inactive—based on the presence of habitats	Not relevant	They are relatively effectively protected under Natura 2000 and the WFD. Nature conservation is regulated by the nature conservation laws of its nine autonomous federal states (Artmann 2018)	Agricultural activities and urban development in former floodplain areas, drainage of wetlands, hydropower production, and flood protection

[a]https://www.gov.si/teme/karte-poplavne-nevarnosti-in-karte-poplavne-ogrozenosti-za-obmocja-pomembnega-vpliva-poplav/.
[b]https://pisrs.si/pregledPredpisa?id=ZAKO1244.
[c]https://pisrs.si/pregledPredpisa?id=URED4840.

(EU) co financing, leaving them vulnerable if priorities shift (Szałkiewicz et al. 2018). Farmers in particular lack incentives or compensation to forgo productive land (Flávio et al. 2017). Politically and institutionally, misalignment and fragmentation hobble action: EU directives can impose conflicting restoration goals (Weigelhofer et al. 2020), while multi-level governance suffers from overlapping agencies and land-ownership patterns (Veidemane 2019; Pröbstl et al. 2024). In summary, experts emphasize that without higher political priority, coherent policies and collaborative governance (and adequate financing and public support) many socio-economic and institutional obstacles will continue to limit river and floodplain restoration in Europe (Cortina-Segarra et al. 2021; Flávio et al. 2017).

Current analyses suggest that allowing rivers to reclaim space for flood storage yields high net benefits compared to intensive development. For example, Dottori et al. Dottori et al. (2023) find that an EU-wide program of flood detention areas (€2.6 billion/year. investment) would reduce river-flood losses by ca 83% while generating a benefit–cost ratio ca 4.2, and it would occupy at most 2% of EU cropland. Likewise, case studies in Germany show enormous service values: Reconnecting floodplain wetlands can retain ~42,000 tN and ~1200 tP/year (avoiding ≳€500 million/year. of pollutant damages) and total floodplain ecosystem services average €4000–4400/ha year. (Heyden and Natho 2022; Natho and Hudson 2024). In summary, published cost–benefit studies thus consistently conclude that the economic gains from flood mitigation (and related water-quality and biodiversity benefits) generally outweigh the opportunity costs of agriculture in restored floodplains (Dottori et al. 2023; Heyden and Natho 2022; Natho and Hudson 2024).

2.3.2 | Floodplain Delineation for Effective Protection

Delineating floodplain boundaries is a critical challenge for effective floodplain protection and management. Clear and consistent definitions are essential for administrative actions and restoration planning. Floodplains can be characterized hydrologically (areas inundated during a 100 year flood), geomorphologically (recent alluvial deposits), or ecologically (habitats adapted to flooding) (Tockner and Stanford 2002). However, definitions vary across regions; for example, in Northern Europe, floodplains may also include fluvio-glacial or lacustrine surfaces that allow river dynamics, even with minimal elevation differences and unconsolidated sediments (Rinaldi et al. 2016). Identifying former floodplains—often disconnected due to human interventions—requires hydrological data, historical records, and digital elevation models (Eder et al. 2022). For conservation purposes, mapping both active and former floodplains supports "river reconnection" projects aimed at restoring natural flood regimes and lateral connectivity (Weigelhofer et al. 2011).

Despite their ecological and regulatory importance, floodplain delineation remains inconsistent and technically demanding across Europe. Among the countries examined, only Czechia, Germany, and partially Italy and Slovakia have undertaken efforts to map former floodplains. In Austria, an ongoing national initiative (expected to be completed within 2026) is developing maps of potential floodplains derived from historical cartographic sources, complementing extensive case studies across various Austrian regions that demonstrate the effectiveness of this approach (e.g., Hohensinner et al. 2013 or, Hohensinner et al. 2021).

These initiatives typically rely on a combination of digital elevation models (DEMs), hydrological data, land cover information, remote sensing, and field surveys. However, such approaches require extensive high-resolution datasets, making nationwide mapping a complex and resource-intensive task (Eder et al. 2022). In Czechia, a national delineation of active and inactive floodplains has been completed, but its coarse scale (1:25,000) limits its applicability for municipal-level planning. To address this limitation, a more detailed methodology has been developed that uses flood hazard maps and soil data to achieve precise delineation at specific locations. Italy integrates floodplain delineation into geomorphic quality assessments under the Water Framework Directive (WFD) and Floods Directive (FD), distinguishing modern floodplains—flat alluvial surfaces inundated during flows slightly exceeding channel-forming discharges (1–3 year return intervals), from recent terraces, which flood less frequently and often represent former floodplain areas disconnected by channel incision or artificial levees (Rinaldi et al. 2016). Slovakia employs LiDAR-derived relative elevation models (REM) combined with GPS field measurements to classify floodplains into three categories: (1) inaccessible floodplains blocked by artificial structures, (2) perched floodplains isolated by river incision, and (3) active floodplains. These examples illustrate that while technical solutions exist, the lack of harmonized approaches and delays in implementation can hinder countries' ability to manage floodplains effectively, restore lateral connectivity, and meet ecological and policy objectives.

The scale commonly used for floodplain delineation in European countries is 1:25,000, with some countries, including Germany, Slovakia, and Italy, using even coarser scales such as 1:100,000. These coarse scales pose significant challenges for the practical application of protection laws, as they lack the resolution needed for precise boundary determination. In most countries, only the floodplains of "important" watercourses have been delineated, with the criteria for "importance" varying. In some countries, such as Czechia, Slovakia, and Germany, this typically refers to large rivers. In others, the selection process is linked to the primary goals of floodplain management, regardless of watercourse size. For example, in Switzerland, floodplains with relatively high ecological quality were prioritized, while in countries like Croatia and Spain, where flood prevention is a key focus, floodplains with the highest flood risk were selected. Austria is the only country to have mapped all floodplains, including those of smaller watercourses. Some German federal states, such as Bavaria, have also completed floodplain delineation for smaller rivers. In Slovenia, the process of all floodplain delineation is ongoing but has been only partially completed thus far.

2.3.3 | Management Priorities—Flood Prevention Versus Nature Protection

Regional differences in floodplain management goals and approaches are evident across Europe, and these priorities strongly influence how floodplains are delineated and protected. In many countries, floodplain protection is closely linked to flood risk management policies, often reinforced by flood insurance schemes. This alignment means that decisions about mapping and restoration are frequently driven by risk reduction rather than ecological objectives, which can shape long-term management strategies.

France provides an illustrative example: its comprehensive flood prevention policy began with the 1982 Compensation Law for victims of natural disasters, introducing state-supported insurance and hazard exposure plans that integrated prevention measures and land-use restrictions. Following severe floods in 2003, legislation was strengthened through the "Hazards, Technological Risks, and Damage Compensation" law, which formalized zoning maps indicating flood hazard areas and associated land-use limitations (Pottier et al. 2005). These measures highlight how a strong emphasis on risk mitigation can accelerate policy development but may also overshadow ecological restoration goals, ultimately influencing the trajectory of floodplain management across Europe.

A comparison of selected European countries reveals that flood prevention is often prioritized over nature conservation in floodplain management (see Figure 2). As a result, floodplain delineation in many countries, including Italy, Spain, Slovakia, Slovenia, or Croatia, is at least aimed at flood hazard assessments, and inactive floodplains are typically excluded from delineation for such purposes. In Slovakia, Relative Elevation Model (REM) data has been used to identify former (inactive) and active floodplains. In Italy, floodplain (inactive) and modern floodplain are delineated for river management purposes (WFD, FD, HD, etc.) through a set of criteria (geomorphic, hydraulic, geo-lithologic, historic, topographic, including DEM). Sl is an exception, where Relative Elevation Model (REM) data has been used to identify former (inactive) floodplains.

Flood protection remains the top priority for floodplain management in the Netherlands, Ireland, Hungary and Spain. In Germany, navigation also plays a significant role in management priorities of large river floodplains. Meanwhile, countries like Slovakia, Ukraine, and Italy adopt a more mixed approach, balancing flood prevention with other goals such as, for example, nature conservation and navigation (Schindler et al. 2016).

To summarize, reducing flood risk and conserving biodiversity are interconnected, as the natural dynamics of floodplains help maintain habitat diversity and regulate flood flows (Schindler et al. 2016; Serra-Llobet, Jähnig, et al. 2022). Still, technical so-called gray flood protection solutions like polders or dams dominate over green solutions. However, in Europe, restoring floodplains is increasingly recognized as an effective way to enhance both flood mitigation and biodiversity (EEA 2025, 2020), with measures such as levee setbacks and wetland restoration improving water storage and connectivity (van Rees et al. 2023; Serra-Llobet, Tourment, et al. 2022). Urban areas rely on upstream catchments to regulate water flow, making integrated watershed-scale planning crucial for balancing flood control with ecological benefits (Gunnell et al. 2019; Suttles et al. 2021). Research confirms that multi-benefit projects, such as floodplain reactivation, can simultaneously reduce flood risks and restore habitats (Zhou et al. 2024; Serra-Llobet, Jähnig, et al. 2022), especially when supported by cross-boundary watershed management (Zhou et al. 2024). Therefore, re-naturalizing upstream floodplains through measures like embankment removal and wetland restoration is a vital strategy for sustainable flood mitigation and biodiversity conservation (EEA 2020; Christopher et al. 2024).

2.3.4 | Protection of Individual Habitats Versus Whole Floodplain Protection

Direct protection of entire floodplains is rare, as conservation efforts tend to focus on specific natural habitats rather than encompassing the whole floodplain. In most countries analyzed for floodplain protection, only selected habitats or spatial units are legally safeguarded. For instance, in Slovakia, parts of floodplains such as meander cut-offs and abandoned channels are included in the National Nature Reservation (NNR) network. These areas are often designated as supra-regional biocentres, representing key components of the country's natural heritage, protected through legally binding regulations.

In other countries, attention is primarily directed toward habitats within the Natura 2000 network or riparian zones prioritized under the Water Framework Directive (WFD) (Jakubínský et al. 2021). According to the European Environment Agency (EEA 2020), Bulgaria and Croatia have the highest proportion of floodplain habitats protected under the Natura 2000 system among EU member states, with 42% of floodplain areas in both countries falling within protected sites. Slovenia follows with 37% of floodplains under Natura 2000 protection, while Italy lags behind at just 14% (see Figure 3). These statistics should be interpreted in context, considering the extent and spatial distribution of floodplains in each country. For example, Italy has identified nearly 29,000 km^2 of floodplains, covering almost 7% of its total area. These floodplains often border major rivers, making them fertile and suitable for agricultural use. In contrast, Slovenia has less than 1300 km^2 of floodplains and they are more commonly found in rugged terrain, characterized by narrow and incised valleys, where human activity is limited due to the higher flood risk.

Integrated floodplain-scale restoration in Europe generally outperforms isolated habitat actions because it reinstates natural hydrodynamics and connectivity across the riverine landscape (Brettschneider et al. 2023; Richards et al. 2020). For example, Stoffers et al. (2022) reported that the Rhine floodplain reaches with permanent two-sided connection to the main channel supported much higher fish abundances and species richness (serving as nurseries) than disconnected channels. Likewise, Paillex et al. (2008) and Reckendorfer et al. (2006) showed that fully reconnected side channels and oxbows hosted many more macroinvertebrate and mollusk taxa than isolated sites, where species richness was markedly lower (Paillex et al. 2008; Reckendorfer et al. 2006). Hydrologic function also differs: reconnecting floodplains increases flood water storage, sediment deposition and nutrient retention, whereas isolated embanked habitats remain hydrologically static. For instance, lowering floodbanks in UK floodplain wetlands boosted flood frequency from 1.7 to 132 events/year and greatly increased habitat hydroperiod diversity (Richards et al. 2020), and Denmark's River Skjern restoration reconnected some 611 ha of floodplain (inundated ~10% of the

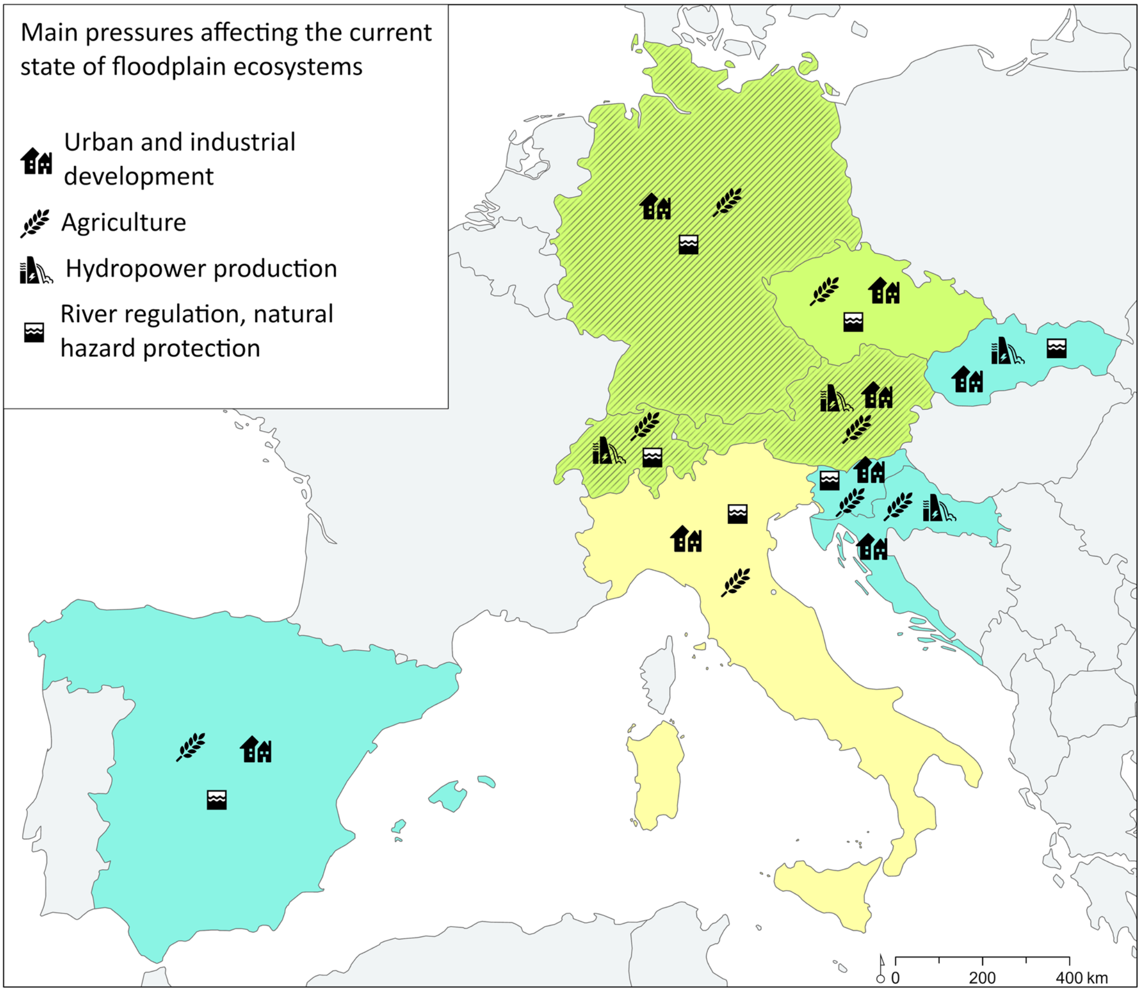

FIGURE 2 | Delineation of floodplains in selected European countries based on the dominant management objective: Floodplain (national coverage) and flood hazard areas (green), floodplain (partial coverage) and flood hazard areas (yellow) and only flood hazard areas (turquoise). The hatched area: Available data on the presence of natural and near-natural floodplains. Pictograms indicate the primary human pressures on floodplains.

year) with attendant sediment and phosphorus deposition into wetlands (Kristensen et al. 2014). These European examples—for example, Skjern's reconnection saw breeding bird species rise from 7 to 31 within 3 years (Kristensen et al. 2014)—illustrate that whole-floodplain approaches can yield multiple biodiversity and water-quality benefits simultaneously, outcomes rarely achieved by isolated habitat projects (which often fail to overcome catchment-scale stressors; Brettschneider et al. 2023).

Broader scientific literature further underscores that restoring connectivity in floodplain systems is key to mitigating catchment-scale stressors and safeguarding ecosystem services, as evidenced by seminal work from Tockner and Stanford (2002) and Bernhardt et al. (2005). In the Netherlands, initiatives have focused on creating extensive networks of wetlands, riverine forests, and grasslands by linking protected habitats. This work has involved collaboration between the Ministry, research institutes, provincial governments, and the mineral extraction industry (Schindler et al. 2016). Similarly, in Germany, the Federal Government's program Germany's Blue Belt (BBD) aims to establish a nationwide network of habitats along federal waterways (LAWA 2014; BMVI, BMUB 2017).

In some countries, specific national laws complement European directives by focusing on the protection of entire floodplains. A notable example is Czechia, where all floodplain ecosystems are formally protected. This comprehensive approach has the potential to support a wide range of ecosystem functions and services, many of which rely on the continuity of longitudinal river ecosystems. Such continuity may be compromised if protection is limited to selected habitats with localized occurrences, as is often the case with networks like Natura 2000 (Hermoso et al. 2012). However, the approach of comprehensive floodplain protection presents several significant challenges, including the complexity of precise floodplain delineation and questions regarding the effectiveness of protection, particularly in intensively utilized floodplains. Although nationwide floodplain protection has been legally mandated in Czechia since the early 1990s, its practical effectiveness has proven limited. A key challenge lies in the need to clearly define and delineate floodplain areas, a task that requires highly accurate spatial data—the first nationwide floodplain maps were only completed in 2024. Another persistent issue is ensuring compliance across such an extensive area. Consequently, while floodplains have long enjoyed formal legal protection, the degree of anthropogenic

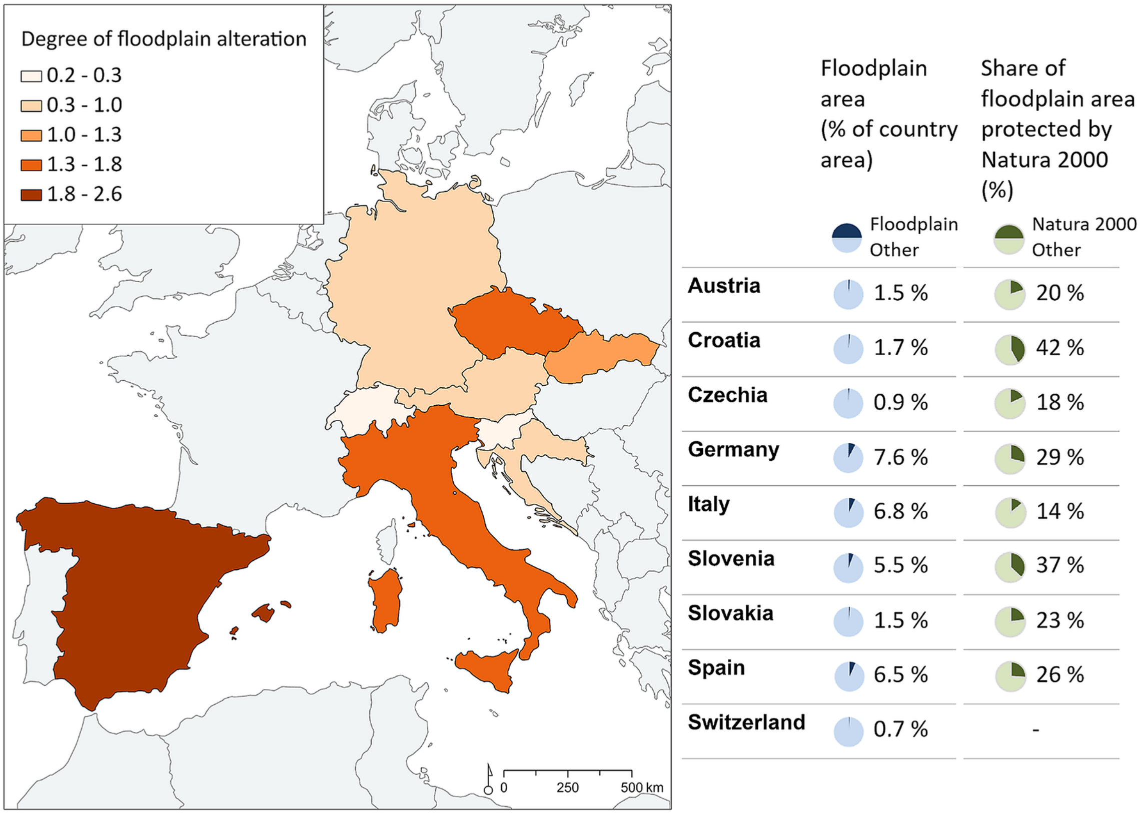

FIGURE 3 | Degree of floodplain alteration by country (index values based on the calculation described by Rajib et al. 2023), share of floodplain areas protected under Natura 2000 (green chart), and proportion of floodplains relative to total country area (blue chart). Alteration is expressed as the proportion of floodplain area that experienced land-use transitions negatively affecting floodplain functions—primarily conversions from wetlands, forests, or grasslands to agriculture or developed land.

degradation remains considerable. In practice, restrictions on land use within floodplains are driven more by the designation of flood hazard zones than by ecologically oriented floodplain conservation. A similar approach has been adopted in Switzerland, where "floodplains of national importance" have been designated. These areas prioritize the preservation of remnants of pristine aquatic and floodplain ecosystems (Brunke 2002). The 1992 Floodplain Decree protects 169 floodplains, with a strong emphasis on preserving their hydrological and morphological integrity while restricting infrastructure development. An inventory maintained by the Federal Office for the Environment (FOEN) identifies and maps 326 floodplains of national importance, representing approximately 20% of Switzerland's total floodplain area (FOEN 2020).

2.3.5 | Conflicts Between Floodplain Conservation and Landscape Development

Floodplain ecosystems are structured by hydrological connectivity operating across lateral, longitudinal, and vertical dimensions, each of which governs ecological and geomorphological processes over space and time. Lateral connectivity facilitates the exchange of water, sediment, nutrients, and biota between rivers and their floodplains and is fundamental to ecosystem functioning (Mason et al. 2025). Longitudinal connectivity ensures the continuity of hydrological and ecological processes along river corridors and is widely recognized as essential for system integrity (Tockner and Stanford 2002; Brierley et al. 2006). As the significance of the hydrological and ecological functions of floodplains becomes increasingly recognized (importance of periodic flooding for maintaining ecological processes and biodiversity in floodplain systems was already emphasized by Junk et al. 1989), there is a growing consensus on the need to restore floodplain connectivity to facilitate active flooding (Funk et al. 2009).

Recent research has expanded the conceptualization of connectivity to incorporate hydrological and morphological processes in conservation planning. Studies have addressed longitudinal system coherence (Moilanen et al. 2008; Hermoso et al. 2011), multidirectional and sub-catchment-scale interactions (Hermoso et al. 2012; Wohl 2017, Wohl et al. 2018, 2021), upstream–downstream propagation of impacts (Linke et al. 2012), and vertical linkages relevant to groundwater-dependent ecosystems (Pringle 2001). Within this framework, restoration of natural hydrological dynamics is widely regarded as a prerequisite for effective floodplain management, as flow regimes shape subsequent physical and ecological processes. Management interventions to restore hydrological regimes include re-establishing natural flow patterns, modifying dam operations, enhancing adaptive governance, and improving management of protected areas (Kingsford et al. 2011). In heavily modified floodplains, river restoration constitutes an integral component of conservation, and the reversibility of hydrological alteration has been proposed as a fundamental objective for sustainable floodplain protection (Boon and Raven 2012; Brunke 2002).

Achieving hydrological recovery frequently requires reducing intensive agricultural use, reinstating natural habitats, and restoring physical river–floodplain interactions. Such measures are necessary to support the multifunctionality of the floodplain ecosystems (Benayas et al. 2008; Schindler et al. 2016). Where natural lateral exchange has been impeded by embankments or infrastructural constraints, structural interventions may be needed to re-establish hydrological connectivity and the associated ecosystem services.

Despite these ecological imperatives, floodplains remain among Europe's most degraded landscapes. Approximately half of the continent's population resides in former floodplain areas, creating substantial human pressure (Tockner et al. 2009). Flat topography, well-developed infrastructure, and proximity to urban centers make floodplains attractive for urban expansion (Tockner and Stanford 2002), while the fertility of alluvial soils underpins their high agricultural value, with nearly 79% of European floodplain areas devoted to agriculture (Tockner and Stanford 2002). These characteristics generate persistent conflicts between hydrological restoration, biodiversity conservation, and socio-economic priorities (Morris et al. 2009).

Social perceptions further constrain restoration initiatives, as floodplains are often viewed as land "lost" to flooding rather than as integral components of riverine ecosystems, reducing the societal acceptance of restoration measures (Fliervoet et al. 2013). Conservation efforts have traditionally prioritized ecological protection over integrated land-use planning (Nielsen et al. 2013), although limiting infrastructure development provides additional societal benefits, such as reduced flood damage (Dixon et al. 2019), improved water quality (Collins et al. 2013; Parkyn et al. 2003), and enhanced ecosystem services (IPCC 2021).

Reconciling biodiversity objectives with policies supporting economic development and food security remains a key challenge (Rouillard et al. 2018; van Rees et al. 2021). Traditional strategies, such as land-use planning and building regulations, aim to prevent uncontrolled development and intensification of floodplain land use. Floodplain management must balance land allocation for biodiversity conservation and human activities, striving for outcomes that benefit both nature and society (Cordingley et al. 2016; Doody et al. 2016). An integrated approach to water management, flood risk mitigation, and nature conservation is essential to implement multifunctional strategies in floodplain management, replacing narrow, sector-specific actions (Schindler et al. 2014).

3 | Conclusion

Floodplain protection in Europe is guided by European directives, but implementation varies widely among member states. Some countries adhere to these regulations, while others prioritize floodplain development, relegating protection to a secondary role. Most European countries lack comprehensive national legislation specifically for floodplain protection, and even where such laws exist, as in Czechia, enforcement is often ineffective. This challenge is especially acute in floodplains already heavily urbanized, where protecting the remaining natural segments is particularly difficult. In this context, EU-funded initiatives can play a crucial role not only in prioritizing the reconnection of former floodplains in non-urban areas, but also in fostering participatory planning processes that align local interests with European conservation objectives. Such approaches are consistent with the EU Biodiversity Strategy for 2030 and the Barrier Removal for River Restoration initiative (EC 2021), which emphasize restoring river–floodplain connectivity while enhancing societal acceptance of restoration measures.

Public perceptions constitute a significant barrier to effective floodplain protection and ecologically oriented restoration. Research shows that how people perceive rivers strongly shapes their support for river and floodplain restoration, including their willingness to pay for ecological improvements (Maa et al. 2025). Misconceptions are widespread: many residents continue to view floodplains as "land lost" to flooding rather than as essential components of fluvial ecosystems, reinforcing expectations that rivers should be controlled and confined. Studies on floodplain and wetland environments further demonstrate that public environmental perceptions, particularly regarding water aesthetics and perceived ecological health, influence levels of acceptance and participation in restoration projects (Cottet et al. 2010). Additionally, social factors such as risk perception, sense of place, and collective memory of past flood events shape how residents evaluate floodplain management strategies and whether they support nature-based approaches (van Heel and van den Born 2020). These findings highlight that transforming prevailing perceptions toward an understanding of floodplains as dynamic ecological systems, critical for biodiversity, hydrological functioning, and climate resilience, is essential for strengthening public support for conservation and restoration efforts.

In many countries, flood control is the primary driver of restrictions in floodplain areas (from the countries targeted in this study, e.g., Spain, Italy, Slovenia, and Croatia). Consequently, floodplain delineation can be focused solely on active or modern floodplains, excluding former or inactive floodplains from management plans. Only a minority of countries delineate floodplains specifically for nature conservation purposes, and even fewer include former (inactive) floodplain areas in this process. Expanding the spatial scope of such delineation is essential, as only broader areas of interest make it possible to restore near-natural hydrological regimes in both active and former floodplains as part of modern conservation strategies.

The primary challenge in floodplain protection lies in identifying areas where frequent flooding can be maintained without conflicting with existing land use and infrastructures. In cases where anthropogenic disturbance is so deep and extensive that potential locations for these "non-conflict" measures are very limited in the catchment (e.g., Mediterranean rivers), then we should focus on areas where the damage could be minor. Nowadays, there are both constructive (e.g., elevated construction on piles leaving the base unbuilt) and economic (compensation to farmers for allowing periodic or occasional flooding of their land in order to minimize the risk to urban areas downstream) measures that can be used to partially recover floodplain processes and make them compatible with a certain degree of human activities. Effective approaches should emphasize preserving or re-establishing natural flow dynamics, as periodic floods, which are critical for sustaining floodplain ecosystems. In developed areas, solutions are more complex but remain a priority for ecosystem restoration. Compromises are possible: in Germany, restoration measures along major waterways are designed as ecological stepping stones compatible with navigation, while in Switzerland, strict preservation of floodplains in good ecological condition has proven effective (BAFU 2020). These insights underscore the need for more robust, ecologically grounded frameworks at both European and national scales to secure the long-term restoration of hydrological processes, enhance landscape-scale connectivity, and preserve the ecological functioning of floodplain systems.

Author Contributions

Jiří Jakubínský: conceptualization (lead), data curation (equal), funding acquisition (lead), methodology (equal), visualization (supporting), writing – original draft (lead), writing – review and editing (equal). **Marcela Prokopová:** conceptualization (equal), data curation (equal), methodology (equal), visualization (supporting), writing – original draft (equal), writing – review and editing (equal). **Barbara Stammel:** data curation (equal), methodology (equal), supervision (equal), writing – original draft (equal). **Ján Babej:** data curation (equal), resources (equal). **Nejc Bezak:** data curation (equal), writing – original draft (equal). **Florian Borgwardt:** data curation (equal), writing – original draft (equal). **Martina Bussettini:** writing – original draft (equal). **Carlo Camporeale:** writing – original draft (equal). **Pavel Cudlín:** conceptualization (equal), methodology (equal), writing – original draft (equal). **Sabine Fink:** data curation (equal), writing – original draft (equal). **Anna Kidová:** data curation (equal), writing – original draft (equal). **Guillermo Palau-Salvador:** data curation (equal), writing – original draft (equal). **Vilém Pechanec:** data curation (equal), methodology (equal), software (equal). **Kristina Potočki:** data curation (equal), writing – original draft (equal). **Carles Sanchis-Ibor:** data curation (equal), writing – original draft (equal). **Lenka Štěrbová:** data curation (equal), resources (equal). **Renata Včeláková:** data curation (equal), software (equal), visualization (lead). **Paolo Vezza:** data curation (equal), writing – original draft (equal).

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data available on request from the authors.

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Managing floodplains using nature-based solutions to support multiple ecosystem functions and services

Enhancing river floodplain management with nature-based solutions: Overcoming barriers and harnessing enablers

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