Aquatic Ecosystems and Environmental Frontiers, Volume 4, Issue 4, December 2026 *ISSN: 3049-186X*
DOI: https://doi.org/10.70102/AEEF/V4I4/AF260409

Recovery Patterns of Aquatic Biodiversity Following the Restoration of Degraded Floodplain Habitats

[1*] Erik Andersson, Nordic Institute for Sustainable Technology Futures, Stockholm, Sweden.

[2] Anna Johansson, Nordic Institute for Sustainable Technology Futures, Stockholm, Sweden.

Abstract: Seasonal flooding, hydrological connectivity, habitat heterogeneity and nutrient exchange are essential for providing a diversity of aquatic communities in floodplain ecosystems. Human activity such as river channelisation, embankments, drainage of wetlands and agricultural development has significantly impacted these ecological processes, causing fragmentation of these systems and loss of biodiversity. The reversion of degraded floodplain habitats represents an opportunity to restore aquatic species diversity, enhance ecological connectivity and ecosystem functioning. This review provides an overview of the recovery trends of aquatic biodiversity after floodplain restoration, and specifically for fish, aquatic macroinvertebrates, riparian animals and habitat-associated biological communities. The review found evidence on the long-term changes in biodiversity, hydromorphological rehabilitation, habitat diversity and indicators of restoration success. Special focus is placed on the differences in recovery rates between taxonomic groups and the effect of the length of time since restoration, the seasonality of the hydrological regimes, and habitat connectivity. The literature reviewed shows that restoration can enhance aquatic biodiversity, with some recovery being more pronounced than others, depending on environmental conditions and the ecological attributes of restored habitats. The review also highlights problems related to the lack of completion of the rehabilitation of the habitats, of monitoring, and also differences in the ecological response between the aquatic and terrestrial ecosystems. A holistic restoration plan which includes historical assessment, hydrological reconnection, habitat diversification and long-term biodiversity monitoring is recommended. The results highlight the need for restoring ecological processes and not just physical habitat conditions in order to restore to sustainable floodplain conditions.

Keywords: Aquatic Biodiversity; Floodplain Restoration; Ecological Recovery; Hydrological Connectivity; Fish Diversity; Macroinvertebrates.

(Submitted: August 25, 2026; Revised: September 28, 2026; Accepted: November 10, 2026; Published: December 30, 2026)

I. Introduction

Floodplain ecosystems are ecologically significant areas that involve periodic interactions between river channels, wetlands, oxbow lakes, floodplain forests, and terrestrial environments. These connected habitats are utilized by a variety of aquatic and semi-aquatic habitats as feeding areas, spawning areas, nursery habitat, and seasonal refuge (Stoltefaut et al., 2024). The nutrient exchange, sediment deposition, transport of organic matter, and biological productivity are controlled by natural floodplain dynamics. Floodplain environments, therefore, have high ecological value in relation to their hydrologic connectivity and availability of a wide variety of aquatic habitat (Pilotto et al., 2019; De Jager & Rohweder, 2012).

Human activities have greatly altered floodplain ecosystems (Lorenz et al., 2018). Changes in natural hydrological processes have taken place because there has been modification to river banks, construction of embankments, agricultural activity, drainage of wetlands, withdrawal of water, and infrastructure development (Claeson et al., 2025; Baart et al., 2013). These disturbances limit the mobility of aquatic organisms, alter water availability, and decrease environmental heterogeneity needed for species coexistence. Degraded floodplain habitats are often subject to changes in species composition, decreases in biological diversity, and deterioration in ecosystem functioning.

In the past few decades, a new ecological management approach has come into use, one that involves the restoration of floodplains, to reverse habitat degradation and enhance freshwater biodiversity. The typical restoration activities include reconnection of disconnected water bodies, restoration of river channels, reconstruction of natural floodplain processes, and enhancement of riparian vegetation and

diversity of habitats (Pander et al., 2024; Lorenz, 2021). The interventions are intended to restore ecological conditions that are conducive to the establishment and maintenance of aquatic communities. Long-term restoration assessments are important not only because biodiversity can continue to evolve several years following the rehabilitation activities, but also because they offer opportunities to validate the general conditions of the site and to verify rehabilitation success.

The recovery of aquatic biodiversity need not be the same for all biological groups. Fish communities can be recolonized as a result of the better connectivity, and macroinvertebrates can exhibit seasonal changes linked to substrate, flow, and habitat availability. Recovery patterns of riparian and terrestrial species may differ as their ecological needs are not the same as those of aquatic species (Pander et al., 2018; Palmer et al., 2010). Therefore, a sufficient number of taxonomic groups and ecological indicators need to be taken into account when assessing restoration success.

Another issue of concern is that of correlation with biological recovery and habitat restoration. In general, increased physical habitat improvements do not result in proportionate increases in physical species diversity. Recovery of genes from source populations, restoration of surrounding habitats, dispersal opportunities, and natural hydrology are all critical to the ecological effectiveness of restoration. The responses of aquatic and terrestrial species also differ, further highlighting the need for multi-level assessment of biodiversity.

The current review highlights the patterns of recovery of aquatic biodiversity after the restoration of degraded floodplain ecosystems. The review addresses the mechanisms affecting recovery, fish and macroinvertebrate community dynamics, habitat heterogeneity, long-term biodiversity recovery patterns, and difficulties connected with restoration evaluation. The review also provides the development of a framework aimed at enhancing floodplain rehabilitation and biodiversity conservation efforts in the long run. The review is divided into seven sections, including section 1 - introduction, section 2 - review methodology, section 3 - ecological mechanisms, section 4 - biodiversity recovery patterns, section 5 - restoration difficulties, section 6 - management recommendations, and section 7 - conclusion.

II. Review Methodology

This study follows a narrative review of the literature to explore aquatic biodiversity recovery in response to restoration of degraded floodplain habitats. The review is based on ten science publications provided for this research, covering ecological engineering, freshwater biology, conservation biology, ecological indicators, river research, environmental science and restoration ecology.

The chosen publications were analysed with regard to their relevance for floodplain restoration, hydrological connectivity, habitat diversity, fish community development, responses of aquatic macroinvertebrates and long-term ecological changes. Research that focused on past floodplain environmental conditions, habitat descriptions after recovery, and variations in biological responses were relevant for understanding ecological mechanisms related to recovery of biodiversity.

Literature was sorted into thematic areas with the restoration interventions, biological responses, ecological indicators, temporal recovery patterns and environmental constraints. A comparison was created to look for linkages between rehabilitation and aquatic biodiversity outcomes. The results were discussed qualitatively, taking into account the differences in the time of the research, the ecological setting, the type of organisms and the aim of the restoration. The present study is not a primary field sampling, a laboratory experiment or a statistical meta-analysis study. Thus, the conclusions are an abstraction of the literature provided and not based on empirical results.

An understanding of ecological mechanisms that affect floodplain biodiversity recovery is developed. Ecological mechanisms that impact recovery of floodplain biodiversity are developed.

III. Ecological Mechanisms Influencing Floodplain Biodiversity Recovery

Hydrological Connectivity and Floodplain Rehabilitation

The hydrological connectivity is a basic driver of the ecological processes of floodplain environments. When river channels are connected to adjacent wetlands through natural channels, water, sediment, nutrients and organisms can move between them. Fragmentation of habitats from artificial barriers and channel alteration can affect these processes and limit the movement of aquatic populations.

Typical activities for restoration of the floodplain include reconnecting isolated water bodies, changing barriers, restoring side channels, and enhancing water exchanges. These interventions can create more feeding, breeding and refuge habitat. To get the ecological advantages, suitable habitats must exist, and organisms must be able to move between connected habitats.

Restoring floodplain conditions based on historical floodplain conditions is important. Changes in channel configuration, historic water levels, land use, and floodplain morphology can be used to identify the degree of ecological modification and potential rehabilitation options to achieve a "natural" channel. Information regarding changes in channel configuration, historic water levels, land use and floodplain morphology can be used to determine the degree of ecological modification and appropriate alternatives for channel rehabilitation to achieve a more "natural" channel. Historical ecosystem conditions need to be taken into account in restoration planning, as do current environmental needs.

Habitat Heterogeneity and Species Establishment

Habitat heterogeneity is the presence of multiple physical and ecological conditions of a floodplain system. Organisms have varying ecological needs, which are linked to different habitats found within shallow wetlands, flowing channels, deep pools, vegetated margins, and seasonally inundated areas. Several habitat types provide more food, breeding, cover, and species diversity.

Habitat structure may not be sufficient for restoring biodiversity in the restoration projects aimed at improving water connectivity. There is a need to restore a variety of aquatic habitats to support a variety of life-history traits. Habitat diversity also offers other environmental conditions during seasonal variation in water supply.

Riparian Vegetation and Ecological Interactions

Riparian vegetation stabilizes the banks, regulates water temperature, holds sediments in place, and provides organic matter to the floodplain to contribute to floodplain biodiversity. Vegetated margins serve as habitats and refuges for aquatic life, as well as link terrestrial and aquatic communities.

Riparian vegetation restoration may help to enhance habitat structure and strengthen the ecological linkages between aquatic and terrestrial landscape resources. However, the process of establishing vegetation and recovery of the associated biological communities may take different paths. When making choices for restoration programs, one needs to assess the aquatic and terrestrial components separately but taking into account their ecological interactions.

IV. Recovery Patterns of Aquatic Biodiversity Following Restoration

Recovery of Fish Communities

Fish communities can be important indicators of ecological conditions in a floodplain since they are closely linked to habitat availability, water connectivity, and environmental quality. Wetlands are often disconnected from river channels, and channel modification often results in poor fish habitat access in degraded floodplain systems.

By reconnecting aquatic environments, opportunities for fish movement, spawning, feeding, and growing up are enhanced. Fish diversity is a useful tool for evaluating restoration success because the diversity of species in a fish community and the changes in species composition may indicate changes in habitat. Long-term assessment is especially important for assessing whether restored habitats are conducive to continued establishment of populations or presence of fish in the short term.

The evaluation of fish recovery should be based on a number of ecological parameters, such as species richness, relative abundance, community composition, functional diversity, and presence of habitat-specialist species. Availability of suitable breeding and nursery habitat also is significant in determining the suitability of restored habitat for the entire habitat life cycle.

Recovery of Aquatic Macroinvertebrates

Aquatic macroinvertebrates consist of insects, molluscs, crustaceans, annelids and other organisms that are associated with aquatic plants, sediments and aquatic substrate. They participate in the decomposition of organic matter, nutrient cycling and the functioning of the aquatic food web as well as in secondary production.

Macroinvertebrate community recovery depends on substrate composition, water velocity, seasonal hydrological fluctuations, habitat and vegetation cover and availability of organic matter. Returned floodplain habitats can create new habitat niches for various groups of macroinvertebrates. However, they may be different in different seasons and habitats, so repeat ecological assessment is required.

Macroinvertebrates can be used to complement aspects of restoration outcomes, including diversity and abundance. Differences in functional feeding groups may also be useful in detecting changes in ecological processes such as organic matter processing and trophic interactions. The taxonomic composition, as well as the functional characteristics, should be monitored.

Recovery of Aquatic and Riparian Communities

Nutrient movement, inputs of organic matter, use of habitat, and movement of species are all interrelated aspects of aquatic and riparian biodiversity. Rehabilitation efforts of floodplain environments can have an impact both on aquatic organisms and on other riparian communities as well as vegetation.

However, the recoveries do not always follow the same pattern among these groups. Water connectivity can have a positive impact on aquatic organisms, while vegetation establishment, soil properties, and availability of suitable terrestrial habitat are more important to terrestrial organisms. Hence, the direct responses of the aquatic environment should be separated from the larger scale changes in the floodplain landscape when assessing biodiversity.

Temporal Development of Biodiversity Recovery

Biodiversity recovery is a dynamic process consisting of a series of steps: environmental improvement, recolonisation of the environment, community restructuring and the development of interaction between the community and the environment. How long each stage will last and how intense this stage will be will vary depending on the type or nature of restoration action, landscape setting, and biological species at issue.

There are four stages in the recovery process that can be illustrated in figure 1. Ecological mechanisms discussed in literature are integrated into the framework, and it serves as a conceptual foundation to assess restoration outcomes.

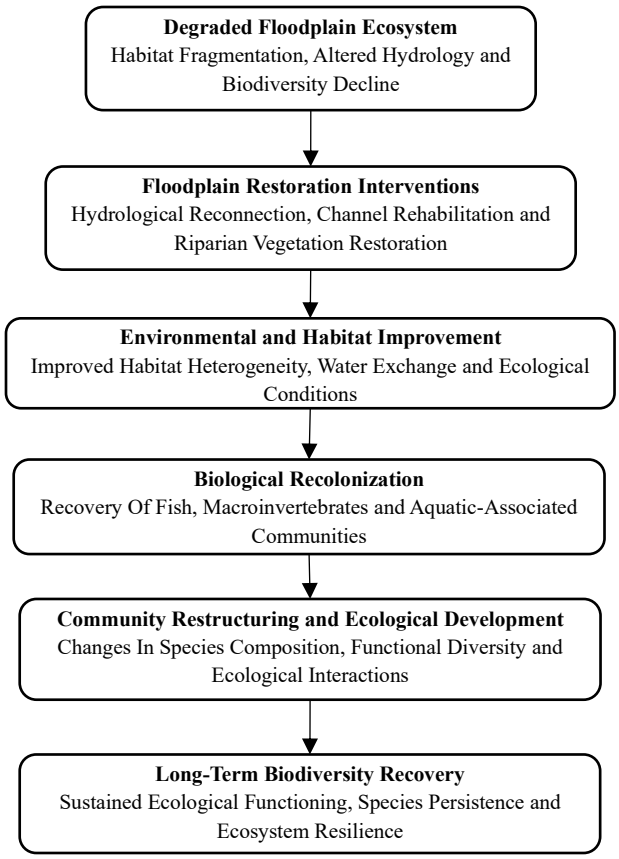


Figure 1: Conceptual Framework of Aquatic Biodiversity Recovery Following Floodplain Restoration

Not all floodplain environments undergo the same recovery process, and not all of them will occur in the same order or at the same time. Suitable habitats that are made available for initial recolonization will enable establishment of stable communities to develop under favorable environmental conditions over extended time periods. Multiple observations are thus required to identify changes as temporary or as evidence of improved biodiversity.

Comparative Assessment of Restoration Interventions

Table 1: Major Floodplain Restoration Interventions and Their Ecological Contributions

Restoration intervention	Ecological mechanism	Expected biodiversity contribution
Historical floodplain assessment Baart et al., (2013)	Identification of historical channel and floodplain conditions	Supports the selection of ecologically appropriate restoration objectives
Aquatic habitat diversification De Jager & Rohweder, (2012)	Improvement in the spatial distribution of aquatic habitats	Increases habitat availability for different aquatic organisms
Hydrological connectivity restoration Pander et al., (2018)	Reconnection of isolated aquatic habitats	Improves organism movement and habitat accessibility
River habitat heterogeneity improvement Palmer et al., (2010)	Reconstruction of diverse physical habitat conditions	Creates opportunities for species coexistence and ecological interactions
Riparian habitat rehabilitation	Recovery of native vegetation and riverbank structure	Improves habitat complexity and aquatic–terrestrial interactions

Aquatic biodiversity is impacted in different ways by various types of restoration interventions. Hydrological reconnection generally enhances the connectivity of water and the movement of organisms, while habitat reconstruction provides more feeding, breeding, and refuge habitat. Riparian rehabilitation

enhances linkages between the aquatic and terrestrial communities. If these interventions are to be effective, they must be part of the overall floodplain ecology.

Table 1 is a comparison of the major approaches used for restoration and their ecological benefits and their pertinence to the recovery of aquatic biodiversity. The comparison also highlights the need for historical environmental information and spatial habitat assessments for the selection of appropriate restoration strategies.

Table 1 reveals that there were varying degrees of success, which suggests a need for multiple complementary interventions to achieve successful restoration. Historical assessment and restoration planning can be supported, and hydrological connectivity and habitat heterogeneity can dictate the ecological opportunities available to recolonizing organisms. Physical habitat improvements should therefore go hand-in-hand with biological monitoring to document restoration success and failure.

Long-Term Biodiversity Responses and Ecological Indicators

Long-term biodiversity assessment is required as ecological communities can continue to change after restoration has been completed. An abundance of species in the first few years doesn't always mean that the ecosystems are stabilizing. Biodiversity patterns can be affected by changes in something over a long period of time, such as the seasonal conditions, population recruitment, and habitat availability or species interactions.

Several complementary indicators should be used in the assessment of restoration results. Species richness is a measure of the number of species reported, and abundance is a measure of the representation of the population. Changes in species dominance and establishment of the habitat-associated organisms can be identified by community composition. Functional diversity is a secondary factor of ecological information that gives additional information about ecological roles and community structure.

Monitoring over time can also facilitate the detection of the difference between short-term colonization and long-term ecological development. There should therefore be repeated biological observations and consistent monitoring procedures coupled with suitable reference habitats to assess the success of restoration.

Table 2: Biodiversity Indicators and Their Relevance to Floodplain Restoration Assessment

Assessment dimension	Principal indicator	Ecological significance
Overall floodplain biodiversity Stoltefaut et al., (2024)	Species richness and community composition	Evaluates long-term changes in floodplain biodiversity
Fish community recovery Pander et al., (2024)	Fish diversity and species occurrence	Indicates aquatic habitat suitability and community development
Aquatic and riparian community responses Lorenz et al., (2018)	Changes in aquatic and riparian biological assemblages	Identifies differences in recovery among ecological groups
Taxonomic response differences Pilotto et al., (2019)	Aquatic and terrestrial species responses	Evaluates the influence of restoration on different biological groups
Macroinvertebrate recovery Claeson et al., (2025)	Seasonal abundance, biomass and diversity	Identifies biological responses to restoration and reconnection
Long-term ecological development Lorenz, (2021)	Continuous changes in biodiversity over time	Evaluates the persistence and development of restoration outcomes

The main dimensions of biodiversity assessment and their ecological significance are summarized in table 2 based on the provided studies on long-term floodplain recovery, fish diversity, community responses, macroinvertebrates, and temporal changes.

The indicators in table 2 illustrate that the number of species is not the only indicator to consider in assessing restoration. Community composition, seasonal community response, and long-term ecological development of the community add to the information about the condition of restored habitats. These

indicators can be used in conjunction to help validate recovery assessments of biodiversity and identify areas in need of additional management.

V. Challenges Affecting Floodplain Biodiversity Recovery

Incomplete Hydrological Restoration

One of the most significant restrictions in the restoration of natural hydrology processes is that they are incomplete. The restoration of channels and wetlands might bring certain advantages from an ecological viewpoint if there are no seasonal flooding and exchange of water. The effects of man-made barriers, water regulation, and altered flood regimes may last and have an influence on the availability of habitats and the migration of organisms. Thus, it is necessary to consider the natural hydrological regime of the entire floodplain, not only the particular water bodies.

Differences in Biological Recovery Responses

Aquatic and terrestrial life-forms respond differently to restoration as they have varying habitat requirements and roles. Establishing hydrological connections can allow some aquatic species to recolonize restored areas while others rely on more extended improvements in the quality of vegetation and substrate. These differences make it difficult to assess the success of restoration and the need for taxon-specific biodiversity indicators.

Insufficient Long-Term Monitoring

Few studies have monitored for long durations following restoration to see if the changes are consistent over time. Changes in species abundance may be temporary due to seasonal conditions or due to temporary improvement in ecosystem function from initial recolonization. Further, restoration assessments may be less comparable if the sampling methods are not uniform or the taxonomic identification is different. Repeated sampling, reference habitats, and several biological indicators should be implemented in long-term monitoring programs.

Environmental and Landscape Constraints

There are external factors that may affect the effectiveness of restoration actions. Pollution, invasive species, changing climatic conditions, agricultural runoff, and sediment buildup can continue to impact restored habitats. Also, projects in highly modified landscapes may find that they have not been recolonized to an extent due to the lack or disconnection of nearby source populations. Therefore, the successful recovery of biodiversity needs to be supported through management of the restoration site and the surrounding river-floodplain landscape.

VI. Recommendations for Improving Restoration Outcomes

Natural hydrology and the restoration of a variety of aquatic habitats should be top priorities in floodplain restoration programs. Historical aspects need to be taken into consideration when designing floodplain conditions. Habitat attributes need to be considered when identifying the objectives for restoration. Wetlands, side channels, vegetation on the edge, and appropriate refuge habitats need to be considered in the design of the restoration process, to cater for different aquatic life forms. Ecological interactions will be improved and complexity of the habitats increased through establishment of riparian vegetation. Monitoring needs to include fish diversity, macroinvertebrate fauna, species richness, community composition, and functional diversity of fish. To improve the quality of restoration assessments, there is a need for better sampling techniques and reference sites. Other factors like pollution and invasive species need to be considered. Long-term development of aquatic and riparian communities and greater attention to seasonal ecological responses should be targeted.

VII. Conclusion

Rehabilitation of aquatic biodiversity after floodplain restoration depends on the process of hydrological connectivity, habitat diversity, environmental conditions, and ecological community development. The literature reviewed indicates that restoration of degraded floodplain environments can increase the number of habitats and allow for recolonization and establishment of aquatic organisms. The fish community, macroinvertebrates, and associated riparian communities offer complementary information for the assessment of ecological recovery. But restoration success is dependent on various factors like habitat characteristics, habitat intensity, biological requirements, and duration of monitoring. Introduction of physical rehabilitation of habitat does not guarantee continuous increase in the levels of biodiversity, especially when hydrological and ecological processes remain disrupted. Therefore, historical assessment, hydrological reconnection, habitat diversification, and monitoring of biodiversity are important parts of restoration planning. Standardized ecological indicators, responses to flood events at the seasonal level, and long-term monitoring in a variety of floodplain habitats should be focused on in future research. Overall, successful floodplain restoration should be assessed by long-term changes in species diversity, community composition, and ecosystem function, leading to long-term conservation and resilience of freshwater ecosystems.

References

[1] Stoltefaut, T., Haubrock, P. J., Welti, E. A., Baker, N. J., & Haase, P. (2024). A long-term case study indicates improvements in floodplain biodiversity after river restoration. *Ecological Engineering*, *198*, 107143. https://doi.org/10.1016/j.ecoleng.2023.107143

[2] Pander, J., Winter, E., & Geist, J. (2024). Ecological indicators for restoration success: development of fish diversity in a large restored floodplain over twelve years. *Ecological Indicators*, *169*, 112920. https://doi.org/10.1016/j.ecolind.2024.112920

[3] Lorenz, A. W., Haase, P., Januschke, K., Sundermann, A., & Hering, D. (2018). Revisiting restored river reaches–Assessing change of aquatic and riparian communities after five years. *Science of the total environment*, *613-614*, 1185-1195. https://doi.org/10.1016/j.scitotenv.2017.09.188

[4] Pilotto, F., Tonkin, J. D., Januschke, K., Lorenz, A. W., Jourdan, J., Sundermann, A., ... & Haase, P. (2019). Diverging response patterns of terrestrial and aquatic species to hydromorphological restoration. *Conservation Biology*, *33*(1), 132-141. https://doi.org/10.1111/cobi.13176

[5] Pander, J., Mueller, M., & Geist, J. (2018). Habitat diversity and connectivity govern the conservation value of restored aquatic floodplain habitats. *Biological Conservation*, *217*, 1-10. https://doi.org/10.1016/j.biocon.2017.10.024

[6] Claeson, S. M., Flitcroft, R. L., & Meyer, K. (2025). Effect of river and floodplain restoration and reconnection on aquatic macroinvertebrates: seasonal responses over time. *Restoration Ecology*, *33*(5), e70079. https://doi.org/10.1111/rec.70079

[7] Lorenz, A. W. (2021). Continuous riverine biodiversity changes in a 10-years-post-restoration-study—Impacts and pitfalls. *River Research and Applications*, *37*(2), 270-282. https://doi.org/10.1002/rra.3729

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

[9] Baart, I., Hohensinner, S., Zsuffa, I., & Hein, T. (2013). Supporting analysis of floodplain restoration options by historical analysis. *Environmental Science & Policy*, *34*, 92-102. https://doi.org/10.1016/j.envsci.2012.10.003

[10] De Jager, N. R., & Rohweder, J. J. (2012). Spatial patterns of aquatic habitat richness in the Upper Mississippi River floodplain, USA. *Ecological Indicators*, *13*(1), 275-283. https://doi.org/10.1016/j.ecolind.2011.06.013