Environmental Reviews

OPEN ACCESS | Introduction

A Roadmap for Implementing the Emergency Recovery Plan for Freshwater Biodiversity

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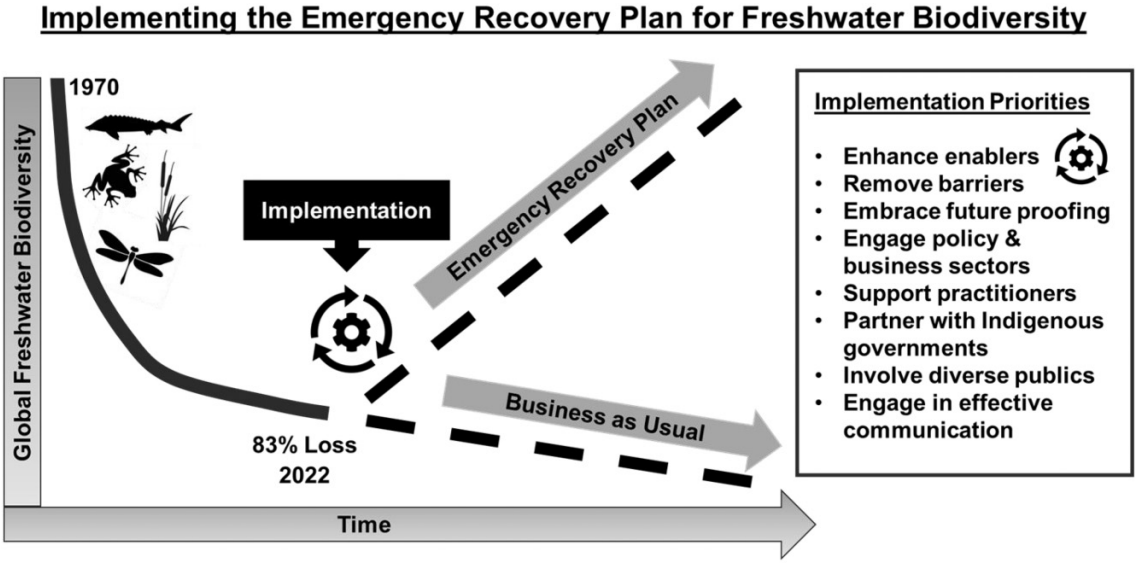
Context

Although hyperbole abounds in the context of environmental issues (Katz 2011), it is entirely appropriate to use the word "crisis" when referring to the current state of freshwater biodiversity (Harrison et al. 2018). There is a growing body of studies (at the regional, national, and international scale) illustrating negative trends in freshwater biodiversity (e.g., He et al. 2019; Jähnig et al. 2021; Isbell et al. 2023; Sayer et al. 2025), indicative of a global decline in essential ecosystem services (Harrison et al. 2018). The numbers are considerable with the World Wide Fund for Nature (WWF) Living Planet Index revealing that average freshwater vertebrate populations are down 83% since 1970, a level of decline more than double that observed in marine and terrestrial systems (WWF 2022). The problems span taxa, ecosystems, regions, and issues. A recent International Union for the Conservation of Nature (IUCN) analysis found that ~1/4 of all freshwater fauna are threatened with extinction (Sayer et al. 2025). For example, 224 (44%) of the 511 freshwater molluscs in Europe are classified by the IUCN as "near threatened" or "threatened" species (Lopez-Lima et al. 2017). In Borneo, the majority of native mussel populations are now imperiled (Zieritz et al. 2018). Such declines are ubiquitous on a global scale (Strayer et al. 2004). The extinction rate for freshwater fishes in North America is estimated to be 877 times greater than the background extinction rate, with an acceleration in loss since the 1950s (Burkhead 2012). Amphibians (the vast majority of which are freshwater-dependent) are the most imperiled taxonomic class on the planet, with a major extinction underway (Ceballos et al. 2020). For some taxa, such as freshwater plants, we simply have no knowledge about their status (Lacoul and Freedman 2006). However, in Canada, for example, 11.7% and 17.9% of all freshwater species of plants and animals assessed were found to be "at risk" or identified as being of "special concern", respectively (Desforges et al. 2022). These declines in specific taxa are paralleled in freshwater habitats as well. Wetland loss from human activities exceeds at least 30% (Hu et al. 2017) and may possibly be higher than 50% (Davidson 2014), with at least 21% loss over the last three centuries alone (Fluet-Chouinard et al. 2023). Due to damming, only 37% of rivers longer than 1000 km remain free-flowing over their entire length (Grill et al. 2019). We will not belabour the point; these example statistics are representative of the overall state of freshwater ecosystems and their biodiversity, which is rather grim (Albert et al. 2021).

The threats facing freshwater biodiversity and ecosystems are numerous and often interacting in complex and unexpected ways (Ormerod et al. 2010; Dudgeon 2019) across spatial scales (Birk et al. 2020). Pollution, fragmentation, water withdrawal, invasive species, and overexploitation are among the most relevant, long-standing, and emerging threats (Dudgeon et al. 2006; Reid et al. 2019). Climate change

Fig. 1. The status quo will presumably lead to the further loss of freshwater biodiversity. By implementing the FW Emergency Recovery Plan, it is possible to begin to "bend the curve" and restore FW biodiversity. We know what to do (as outlined in the various papers in this special issue), so the biggest challenge is implementation. There is dire need to focus on implementation priorities (indicated on the figure) to ensure that the FW Emergency Recovery Plan is implemented at relevant scales (regional, national, international) and in a way that engages all relevant actors.



also serves as a "threat multiplier" (Smol 2010), whose interactions with other stressors can be synergistic (Dudgeon 2019; Dodson et al. 2020; Barbarossa et al. 2021). Inadequate governance and poor management of freshwater ecosystems and water resources either causes or compounds these threats.

Collectively, these threats do not just impact freshwater biodiversity and ecosystems, but also the people who depend upon them (Basurto et al. 2013). We acknowledge that essential human activities such as drinking water, electricity generation, agriculture, and transportation require freshwater resources. Yet some freshwater resource development and exploitation achieve short-term benefits at the expense of long-term sustainability, and those benefits are often distributed unequally, with collateral impacts disproportionately affecting disadvantaged groups in society (e.g., Sherman et al. 2015). Freshwater biodiversity and ecosystems yield numerous ecosystem services, spanning from nutrition for some of the world's most food insecure peoples to supporting livelihoods (Postel and Carpenter 1997; Lynch et al. 2016, 2023; Parmesan et al. 2022). In fact, freshwater resources are the basis for many cultural practices and religions (Lynch et al. 2023). There is clear evidence that the impacts (direct and indirect) of humans and associated threats on freshwater ecosystem services are diminishing the values that can be derived in the future (Naiman and Dudgeon 2011; Dodds et al. 2013).

For years, the scientific community has been calling the attention to the threatened state of freshwater ecosystems and of their biodiversity loss (e.g., Strayer and Dudgeon 2010; Carpenter et al. 2011; Gleick 2018; Albert et al. 2021; Kuiper 2023). While there is little evidence that these calls have promoted substantial changes in trajectories for freshwater ecosystems and biodiversity (Dudgeon and Strayer 2025), a few initiatives show promise. For instance, WWF has spearheaded the development of the "Emergency Recovery Plan for Freshwater Biodiversity" (see Tickner et al. 2020; herein, the "FW Emergency Recovery Plan"). The term "emergency" was used intentionally to acknowledge the urgency needed in addressing the crisis. Overall, the FW Emergency Recovery Plan consists of six actions that, if embraced, would "bend the curve" (sensu Mace et al. 2018) of freshwater biodiversity loss globally (Fig. 1). The actions are as follows:

1. Accelerating the implementation of environmental flows.
2. Improving water quality.
3. Protecting and restoring critical habitats.
4. Managing the exploitation of freshwater ecosystem resources, especially species and riverine aggregates.
5. Preventing and controlling non-native species invasions.
6. Safeguarding and restoring river connectivity.

The FW Emergency Recovery Plan has served as an effective framework for broad policy influence, such as in the lead up to the 15th Conference of the Parties of the Convention on Biological Diversity (CBD). However, the original article by Tickner et al. (2020) contains insufficient information for those intending to use it to operationalize each of the six actions that would lead to the recovery of freshwater biodiversity. Accordingly, there is a need to take a deeper dive into each of these six actions to synthesize relevant evidence required to implement the recovery plan. Also, case studies can further exemplify how these actions are being implemented in both lower and higher income countries and thus inform delivery of international agreements and initiatives such

as the CBD Kunming-Montreal Global Biodiversity Framework (see https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf and Cooke et al. 2023) and the Freshwater Challenge, launched by eight governments during the 2023 UN Water Summit (https://wwf.panda.org/wwf_news/?7942466/Launch-of-Freshwater-Challenge).

To that end, we assembled a collection of papers focused on a deeper examination of each of the six FW Emergency Recovery Plan actions. In addition to having a paper exploring barriers to and opportunities for implementation of each of those actions, we also included a paper focused on understanding and influencing the wider policy context for such efforts (Tickner et al. 2025) as well as a paper that considers how to future-proof such actions (Lynch et al. 2024). This preface provides the context and briefly summarizes key messages arising from each paper in the special issue. Underpinning all papers in this collection is the goal of ensuring that we include and amplify voices from around the globe that represent different regions, identities, knowledge systems, career stages, sectors, and roles. The core papers have accordingly been authored by a diverse group of experts and include case studies that attempt to highlight how the various high-level actions (and associated response measures) relate to different regional contexts.

Synopsis of content in the special issue

Accelerating implementation of environmental flows

Arthington et al. (2024) outline threats arising from hydrological alterations caused by dams, freshwater overuse, and climate change, and identify critical factors that enable recovery of freshwater biodiversity in flow-stressed rivers. These enabling factors include overarching environmental flows (e-flows) legislation and participatory governance, sustained financial and human resources, diverse stakeholder engagement and co-production of western and Indigenous knowledge, capacity training and research, and collaborative monitoring of ecological and social–economic outcomes. Biodiversity and societal outcomes from e-flow implementations can be strengthened by exploring trade-offs among water users, removing or retrofitting water infrastructure to facilitate e-flows and connectivity, and adaptations to address climate-change scenarios.

Improving water quality

Kelly et al. (2026) outline the many contamination pathways and diverse array of pollutants that contribute to degraded water quality and identify response options to improve water quality. Response options include informing action through monitoring and understanding pollutant trends and ecosystem impacts, regulation and enforcement to reduce pollutant loads, substitute harmful substances, and ensure that polluters pay, improving the management and remediation of pollutants at source, in situ, and across catchments, and addressing the systemic drivers of pollution through education, incentives, and market mechanisms.

Protecting and restoring critical habitats

Piczak et al. (2024) synthesize the threats associated with habitat fragmentation, degradation, and loss, and outline specific response options to save freshwater biodiversity. These response options include legislating the protection of healthy and productive freshwater ecosystems; prioritizing habitats for protection and restoration; enacting durable protection; conserving habitat in a coordinated and integrated manner; engaging in evidence-based restoration using an adaptive management approach; ensuring that potential freshwater habitat alterations are mitigated or off-set; and enabling future-proofing of protection and restoration actions. Expected challenges involve (1) institutional and management practices and laws (e.g., limited resources), (2) scientific uncertainties (e.g., regarding climate change), and (3) social and political goals (e.g., shifting political priorities).

Managing the exploitation of freshwater ecosystem resources, especially species and riverine aggregates

Cooke et al. (2024) outline the threats arising from the exploitation of freshwater biota and aggregate resources (e.g., sand, gravel, boulders), and identify response options to ensure that methods and levels of extraction are sustainable and allow recovery of overexploited freshwater biodiversity and ecosystems. Response options for managing species exploitation include strengthening assessment and reporting, using science-based approaches to reduce overexploitation and support recovery, embracing community engagement, and building or tightening legislation. Response options for managing exploitation of freshwater aggregate resources include reducing demand for extraction, strengthening governance, reporting, and monitoring of environmental impacts, and promoting the restoration of degraded ecosystems or compensating for losses.

Preventing and controlling non-native species invasions

Britton et al. (2023) emphasize that the most effective management measure to protect freshwater biodiversity from non-native species is to prevent their introduction from occurring (e.g., inspecting and quarantining imports, decontaminating possible vectors). If this is unsuccessful, the early detection of non-native species enables the implementation of rapid response measures to prevent population establishment, dispersal, and impact (e.g., intense eradication efforts). Where these steps fail to prevent the invasion from progressing, management response options are then usually limited to methods that aim to control and/or contain the non-native species (e.g., sterile male release techniques). Developments in invasion risk assessment enable non-native species to be prioritized according to their invasion risk; for species that are already invasive, these assessments help ensure that the management responses are commensurate with the risks to freshwater biodiversity. Issues associated with non-native species in freshwaters include their presence often being a symptom of a degraded freshwater, rather than the species being the main driver of biodiver-

sity loss, and so management requires more holistic interventions that aim to more generally restore the freshwater environment.

Safeguarding and restoring river connectivity

Thieme et al. (2024) summarize measures for maintaining and restoring river connectivity, including system-scale planning for energy and water resources to limit the loss of freshwater connectivity; putting in place protections for keeping critically important freshwater habitats connected; mitigating impacts on freshwater ecosystems via barrier design, fish passage, or implementation of environmental flows; and restoring freshwaters via barrier removal and reconnection of rivers, wetlands, and floodplains, and via active management of groundwater recharge.

On future proofing freshwater biodiversity protections

Lynch et al. (2024) warn that the FW Emergency Recovery Plan will not bend the curve of biodiversity loss if it only considers response options to address historic and current conditions. Uncertainty related to climatic, demographic, geopolitical, socio-economic, and cultural contexts make historical baselines somewhat less relevant and conventional conservation and restoration objective targets potentially maladaptive (Barnett and O'Neill 2010). "Future-proofing" is a concept that explicitly addresses future uncertainties and surprises. It refers to the process of anticipating future events and developing methods to mitigate or minimize plausible stressors and shocks to a system (Rehman et al. 2017). Future-proofing the FW Emergency Recovery Plan can safeguard against future known uncertainties (e.g., climate change, emerging pollutants) and build resilience to withstand future unknown uncertainties (e.g., unexpected non-native species, algal blooms, diseases) and unanticipated surprises (see table 1 in Lynch et al. (2024) for examples).

On policy

Tickner et al. (2025) describe the key sectors that the international freshwater conservation and science communities should seek to influence to address underlying drivers of freshwater biodiversity loss, such as water resource management, agriculture, and energy. They describe major risks and opportunities emerging from current sector-specific policy discourses (e.g., public and private sector funding) and suggest priorities for research and advocacy interventions. Freshwater biodiversity issues cannot be addressed without significant inter-sectoral collaboration and coordinated policy development and action. There is much that can be done to embrace a more systemic, driver-focused approach to freshwater conservation research to ensure that freshwater biodiversity is considered in decisions related to both policy and business.

From roadmap to implementation

The evidence-base to guide management responses is ever-growing and, although some research gaps remain (Arthington 2021; Harper et al. 2021; Maasri et al. 2022), the bigger challenge lies in decision-making and implementation. We need, for example, to determine the most effective means of communicating the need for, and benefits of, action to different audiences, including governments (from local to regional to national to international bodies), other decision-makers, and diverse publics around the globe drawing on insights from behavioural and cognitive sciences (Toomey 2023). There is also immediate need to embrace different knowledge systems (e.g., Indigenous ways of knowing, stakeholder knowledge) to ensure that all relevant forms of evidence are considered when identifying the best management measures for a given scenario. All relevant actor groups (including rights holders and their rights to self determination as outlined in the UN Declaration for the Rights of Indigenous Peoples; https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf) need to be included in decision-making processes (Birnie-Gauvin et al. 2023).

Twardek et al. (2021) and Cooke and Birnie-Gauvin (2022) emphasized the important role that will be played by practitioners who are frontline workers as it relates to freshwater protection, management, and restoration. While large-scale policy changes at the level of regional and global governance (e.g., UN, global agreements such as Conference of Parties Biodiversity; see Gonçalves and Hermoso 2022) can surely affect change, those governance-level efforts can only be as impactful as the on-the-ground actions that can be undertaken. Throughout the papers in the special issue, there are case studies from high-income and low-income regions that range from localized community-level initiatives to multinational policy initiatives.

The freshwater biodiversity crisis is often overshadowed by other more visible issues. However, demonstrating the value of freshwater biodiversity (see Lynch et al. 2023) yields many stories that can be shared with the public and politicians, on the path to generating political will for action. We also need to capture and share success stories where governments, communities, and other organizations work alone or together to implement aspects of the FW Emergency Recovery Plan. Communication activities can use a combination of hope and fear to best elicit engagement (Kidd et al. 2019) and can be framed intelligently and adaptively to resonate with the values and priorities of target audiences in specific contexts. There is need for a coherent approach to planning effective communication efforts that can be applied in different contexts and with different audiences in mind. There is also an opportunity to use change models (see Reddy et al. 2017) to ensure that all elements of the pathway (e.g., from any communication or public engagement efforts through to behaviour change and associated actions related to the FW Emergency Recovery Plan) yield tangible improvements in freshwater biodiversity.

Conclusion

In this special issue, we have provided insights on how the world can implement the FW Emergency Recovery Plan

(summarized in Fig. 1). Notably, we have also provided examples (case studies) where actions have been implemented with some success. Given that we are facing a critical environmental state with freshwater ecosystems and species, all constructive efforts, no matter the scale, are helpful. However, actions that are conducted in a systematic manner (Linke et al. 2011) and across relevant scales (e.g., using a watershed approach; Brumm et al. 2022) are particularly relevant. We also acknowledge that resources for implementing the plan will be limited such that it will be necessary to prioritize efforts (see Linke et al. 2019). Keeping an eye on the future (i.e., future-proofing) in all efforts can help ensure that actions are durable (sensu Higgins et al. 2021) in a changing world.

The policies related to freshwater ecosystems likely benefit from adopting a deeper recognition of the connections between water, biodiversity, and people such that relevant policies, ranging from global to local scales (Dudgeon and Strayer 2025) and involving social actors of different sectors, are improved, created, or strengthened. Fortunately, freshwater biodiversity has recently received more attention in global policy arenas (Gonçalves and Hermoso 2022; Cooke et al. 2023), but more work is needed. Governance structures that support freshwater biodiversity protection and restoration are not sufficiently present in many global regions, making it difficult or impossible to effectively implement the FW Emergency Recovery Plan actions. Building capacity for informed action and strengthening governance remain priorities, particularly in the vulnerable regions where much of the freshwater biodiversity exists and is used by locals, and where the consequences of that loss will be even more profound for people and the planet.

Finally, we acknowledge that implementing the plan will require the work of many actors, including scientists, practitioners, rights holders, stakeholders, politicians, business leaders, investors, and voters. There are many ways for these individuals and groups to become involved in enacting the FW Emergency Recovery Plan and bending the curve for freshwater biodiversity. We now know how to operationalize the plan; the next step is putting those strategies into action!

Positionality statement

The special issue was coordinated by Cooke, Lynch, Tickner, and Abell. Smol served as Editor for the papers in the collection. The other authors represent leads of various papers within the special issue or individuals that were particularly engaged in the process. The first author acknowledges the stewards of the lands and waters where we live, work, and play recognizing that many of us are settlers and are guests on the traditional territories of Indigenous peoples. We also acknowledge the varied conditions and contexts in which various contributors to our special issue engage with freshwaters—having different professional roles, active in varied socio-cultural and geo-political contexts, and operating in systems with varied capacity, governance stability, and freedoms. The freshwater biodiversity crisis impacts people around the globe, and similarly, to implement the Emergency Recovery Plan requires broad engagement across all continents, biomes, countries, and regions. We hope that the papers presented here serve as a roadmap for bending the curve for freshwater biodiversity.

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John P. Smol served as Editor-in-Chief at the time of manuscript review and acceptance; peer review and editorial decisions regarding this manuscript were handled by another editorial board member.

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Conceptualization: SJC, AJL, DT
Project administration: SJC
Visualization: SJC
Writing – original draft: SJC, AJL, DT
Writing – review & editing: SJC, AJL, DT, RA, MP, AHA, MT, DP, JRB, TD, KB, SJO, FAM, RR, JPS

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