# Bending the Curve of Global Freshwater Biodiversity Loss: An Emergency Recovery Plan

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*Despite their limited spatial extent, freshwater ecosystems host remarkable biodiversity, including one-third of all vertebrate species. This biodiversity is declining dramatically: Globally, wetlands are vanishing three times faster than forests, and freshwater vertebrate populations have fallen more than twice as steeply as terrestrial or marine populations. Threats to freshwater biodiversity are well documented but coordinated action to reverse the decline is lacking. We present an Emergency Recovery Plan to bend the curve of freshwater biodiversity loss. Priority actions include accelerating implementation of environmental flows; improving water quality; protecting and restoring critical habitats; managing the exploitation of freshwater ecosystem resources, especially species and riverine aggregates; preventing and controlling nonnative species invasions; and safeguarding and restoring river connectivity. We recommend adjustments to targets and indicators for the Convention on Biological Diversity and the Sustainable Development Goals and roles for national and international state and nonstate actors.*

*Keywords: river restoration, wetlands, freshwater conservation, Sustainable Development Goals, Convention on Biological Diversity*

**Humans have caused widespread planetary change,** ushering in a new geological era, the Anthropocene (a term first coined in the 1980s by Eugene F. Stoermer, a freshwater biologist). Among many consequences, biodiversity has declined to the extent that we are witnessing a sixth mass extinction (Ceballos et al. 2017). Recent discourse has emphasised the triple challenge of bending the curve of biodiversity loss (Mace et al. 2018) while also reducing climate change risks and improving lives for a growing human population. In 2020, governments will review international agreements relevant to this challenge, including the Convention on Biological Diversity (CBD) and the Sustainable Development Goals (SDGs). There is a brief window of opportunity now to set out recommendations that can inform these agreements and guide future policy responses.

Nowhere is the biodiversity crisis more acute than in freshwater ecosystems. Rivers, lakes, and inland wetlands (such as deltas, peatlands, swamps, fens, and springs) are home to an extraordinary diversity of life. Covering less than 1% of Earth's surface, these habitats host approximately one-third of vertebrate species and 10% of all species (Strayer and Dudgeon 2010), including an estimated 70 species of freshwater-adapted mammals, 5700 dragonflies, 250 turtles (Balian et al. 2008), 700 birds (IUCN 2019), 17,800 fishes (Fricke et al. 2019), and 1600 crabs (Neil Cumberlidge, Northern Michigan University, 4th June 2019). The levels of endemism among freshwater species are remarkably high. For instance, of the fish species assessed for the freshwater ecoregions of the world, over half were confined to a single ecoregion (Abell et al. 2008).

Freshwater ecosystems also provide services to billions of people, including impoverished and vulnerable communities (Lynch et al. 2016). However, the management of freshwater ecosystems worldwide has frequently prioritized a narrow range of services for macroeconomic benefit at the expense of habitats, flora and fauna, and the diverse benefits they provide to communities. Consequently, the current rate of wetland loss is three times that of forest loss (Gardner and Finlayson 2018), and populations of freshwater vertebrate species have fallen at more than twice the rate of land or ocean vertebrates (Grooten and Almond 2018).

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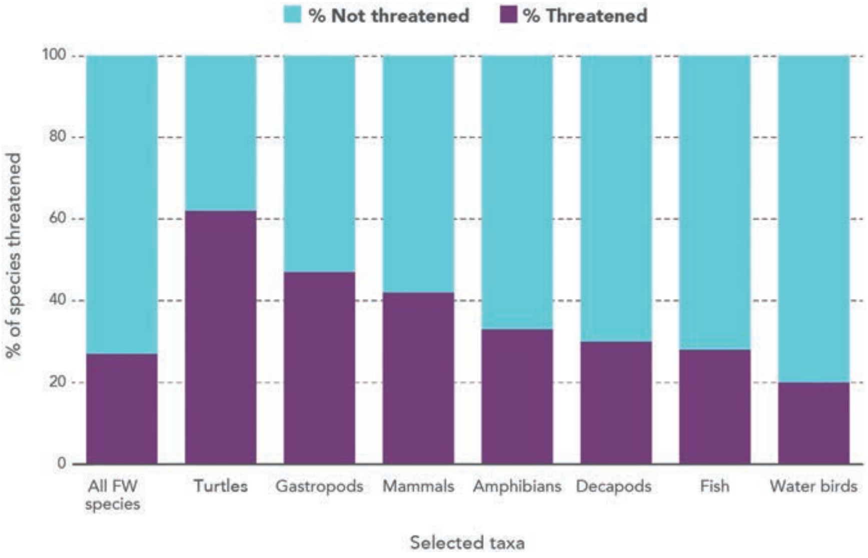


***Figure 1. Proportions of freshwater taxa threatened with extinction. Source: IUCN (2019).***

Of the 29,500 freshwater dependent species so far assessed for the IUCN Red List, 27% are threatened with extinction. Among these, an estimated 62% of turtle species, 47% of gastropods, 42% of mammals, 33% of amphibians, 30% of decapod crustaceans (crabs, crayfish, and shrimps), 28% of fishes, and 20% of birds are at risk (figure 1; IUCN 2019). Populations of freshwater megafauna, defined as animals that reach a body mass of 30 kilograms, declined by 88% from 1970 to 2012, with the highest declines in the Indomalaya and Palearctic realms (−99% and −97%, respectively; He et al. 2019).

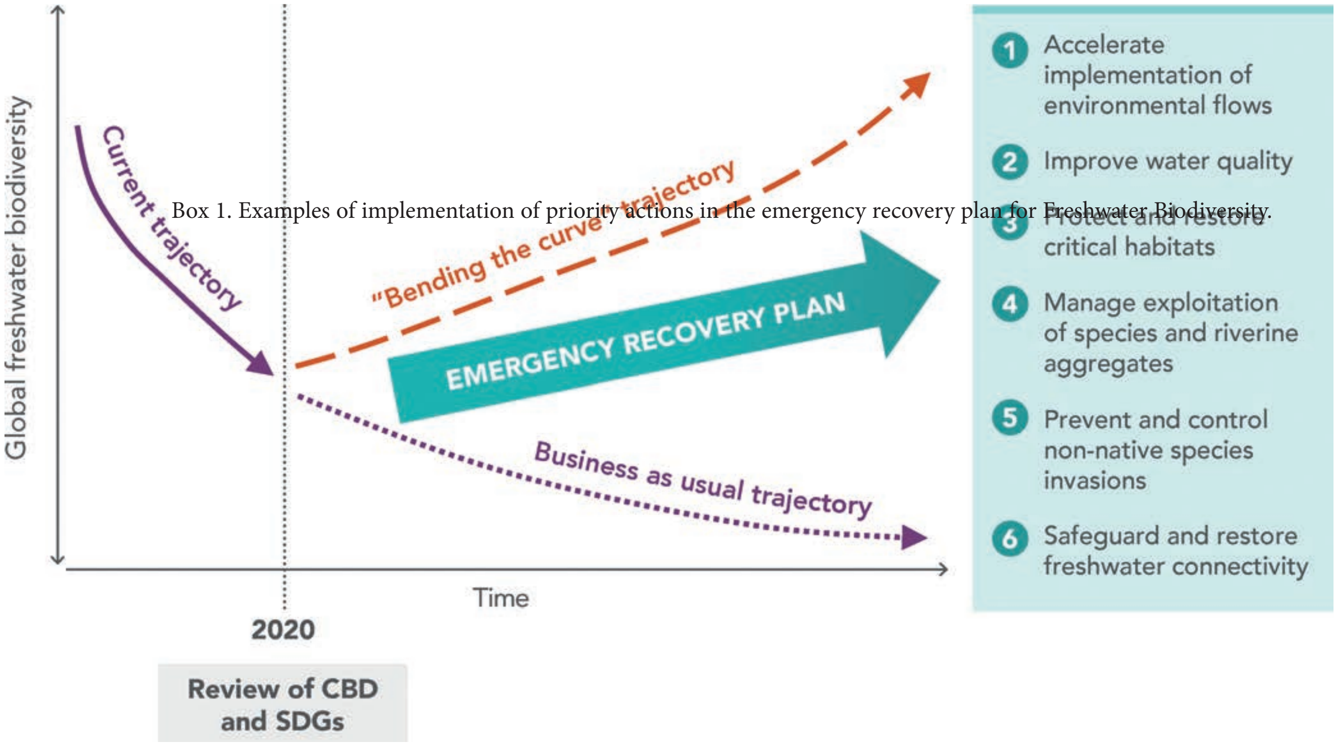
The causes of these declines have been comprehensively synthesised (e.g., Dudgeon et al. 2006, Reid et al. 2019), but no global framework exists to guide policy responses commensurate with the scale and urgency of the situation, and actions to safeguard freshwater biodiversity have been “grossly inadequate” (Harrison et al. 2018). Recommendations to address immediate threats to and underlying drivers of global biodiversity loss have focused mainly on terrestrial ecosystems, such as forests and grasslands (e.g., Kok et al. 2018) or have emphasised particular conservation strategies, such as enhancing protected area coverage and condition (e.g., Dinerstein et al. 2019, Visconti et al. 2019). Although they are valuable, these proposals have either assumed, simplistically, that measures designed to improve land management will inevitably benefit freshwater ecosystems, or they have neglected to consider freshwater biodiversity at all. Anthropogenic threats distinct to freshwater ecosystems, especially those linked to hydrological regimes and loss of connectivity, have been insufficiently considered in international conservation agreements and conventional conservation strategies, impeding investment in appropriate policy and management measures and contributing inadvertently to the disproportionately high losses of freshwater species and habitats.

In this article, we present an Emergency Recovery Plan to reverse the rapid worldwide decline in freshwater biodiversity. This plan extends the concept of species recovery plans established in legislation such as the US Endangered Species Act 1973 and the Australian Environment Protection and Biodiversity Conservation Act 1999. Given the speed and extent of collapse in freshwater biodiversity, parallels can be drawn with postdisaster recovery situations, and we have deliberately used the word *emergency* to convey the urgency with which conservationists, water managers, stakeholders, and policymakers must act to avoid further deterioration of habitats and to promote recovery of biodiversity. The plan is novel in this conceptual foundation, in its focus on solutions (rather than documentation of threats) and in its explicit recommendations for international agreements, especially the CBD and the SDGs.

## The Emergency Recovery Plan: Priorities for action

The plan is structured around six priority actions (figure 2). Five of these focus on the major causes of freshwater biodiversity loss described by Dudgeon and colleagues (2006): flow alteration, pollution, habitat degradation and loss, overexploitation of species, and invasive nonnative species (INNs). In the priority action on overexploitation we have considered exploitation of abiotic substrates, such as sand and gravel, alongside biota, reflecting rising concerns about the damage to freshwater ecosystems caused by rapid expansion of riverine aggregate mining (UNEP 2019). We have also defined a sixth priority action on connectivity because of the distinct and pervasive role of dams and other infrastructure in fragmenting freshwater ecosystems and disrupting movements of water, species, sediments, and nutrients (Grill et al. 2019). Just as threats to freshwater biodiversity loss often act synergistically (Craig et al. 2017), so these priority actions should be considered and planned coherently for maximum efficiency and impact. Measures to address one cause of biodiversity loss can, in many contexts, help address other causes too.

Given the scale of the crisis, the plan must be ambitious. But it must also be technically feasible and pragmatic in political and socioeconomic terms. As we outline in box 1, each priority action has already been implemented successfully in one or more situations across the globe, providing proof of concept and lessons that can inform how to scale up efforts.



Box 1. Examples of implementation of priority actions in the emergency recovery plan for Freshwater Biodiversity.

*Figure 2. The Emergency Recovery Plan for freshwater biodiversity: Six priority actions for global action to bend the curve of freshwater biodiversity loss that should be reflected in the post-2020 biodiversity framework. Threats to freshwater biodiversity are often synergistic so coherent planning of interacting priority actions to address such threats is necessary.*

Below, for each priority action, we briefly review the problem, potential policy and management solutions, and the current implementation status of these solutions.

**Action 1: Accelerate implementation of environmental flows.** Water management for power generation, for flood risk reduction, or to store and deliver water for agricultural, industrial, or domestic uses changes the quantity, timing, and variability of water flows and levels. In doing so, it directly alters the physical availability of freshwater habitats, their ambient conditions, connectivity between habitats, and ecosystem processes such as sediment flow. These alterations, in turn, affect functional links between hydrological regimes and the life histories of freshwater species (Bunn and Arthington 2002) and therefore contribute substantially to losses of freshwater biodiversity. Climate change exacerbates flow alteration in many situations (Döll and Bunn 2014).

Maintaining or restoring ecologically important attributes of hydrological regimes improves biodiversity outcomes (Poff et al. 1997, Bunn and Arthington 2002, Olden et al. 2014). The science and practice of environmental flow assessment enables identification and quantification of these attributes. A sophisticated methodological toolbox now exists for developing environmental flow scenarios and recommendations in a wide range of water resource management contexts, from minimally altered to heavily managed freshwater ecosystems (Acreman et al. 2014, Poff et al. 2017). Many environmental flow assessment tools consider desired socioeconomic and cultural objectives alongside biodiversity goals, aiding incorporation of recommendations into river basin plans, water allocation regimes, and design and operation of water infrastructure. The 2018 Brisbane Declaration and Global Action Agenda on Environmental Flows set out 35 recommendations to accelerate implementation (Arthington et al. 2018).

Environmental flows have been incorporated into policies in many jurisdictions (Le Quesne et al. 2010). As long ago as 1968, the United States passed the Wild and Scenic Rivers Act (1968), which mandates the conservation of rivers of oustanding natural, cultural and recreational value, including through maintenance of their free-flowing character. More recently, the European Union has recommended the inclusion of environmental flows in river basin management plans required by the EU Water Framework Directive (European Commission 2015), the nine Nile Basin countries have agreed a common environmental flow assessment strategy (NBI 2016), and China has integrated environmental flows into environmental impact assessment laws (Chen and Wu 2019). Examples of environmental flow implementation have been documented from diverse contexts (Harwood et al. 2017), but these are currently isolated successes. Human demands for water will increase in some

**Box 1. Examples of implementation of priority actions in the Emergency Recovery Plan for Freshwater Biodiversity.**

## Accelerate implementation of environmental flows

**River basin planning.** Environmental flows have been incorporated into water legislation in South Africa and implemented through legally mandated catchment management agencies—for example, on the Crocodile River.

**Water allocation.** Mexico's Water Reserves initiative sets sustainable water allocation limits for 189 rivers across the country, taking account of environmental flows.

**Infrastructure design and operation.** Environmental flows to benefit downstream fisheries are now part of the operational regime of the Three Gorges Dam, China.

## Improve water quality to sustain aquatic life

**Waste water treatment.** The EU Urban Waste Water Treatment Directive has led to widespread reduction in sewage pollution.

**Regulation of polluting industries.** In Singapore, a large-scale project was launched in the 1970s to clean up the Singapore River and restore aquatic life, including through removal and relocation of pollution from pig and duck farms and from industry while encouraging business and residential development along the waterfront.

**Market instruments.** Around Lake Taupo, New Zealand, catchment scale nitrogen caps combined with farm-based permits and trading and establishment of a trust fund to help reduce costs of nitrogen-reducing practices for farmers, has helped to tackle persistent diffuse pollution problems linked to pastoral agriculture.

**Improved agricultural practices.** Better management practices on cotton and sugarcane farms in India and Pakistan, encouraged by market-based initiatives such as the Better Cotton Initiative and Bonsucro, have led to reductions in pesticides and fertilizers reaching watercourses.

**Nature-based solutions.** In China, restoration efforts for floodplain lakes along the central Yangtze River have resulted in improvements in lake water quality with consequent enhancement of fisheries and floodplain biodiversity.

## Protect and restore critical habitats

**Protected areas.** Among many examples of successful protected area designation and management, the gazettement by the government of Colombia of the entire 825,000 hectares Bita River basin (a subbasin of the Orinoco) as a Ramsar site is a rare example of a free-flowing river and its entire basin being protected through an international designation.

**Land-use planning or markets for ecosystem services.** The New York City Watershed Agreement has stimulated improved land use planning and management to protect and restore ecosystem processes in the Castkills–Delaware watersheds, safeguarding urban water supplies in a cost-effective way in the process.

**Habitat restoration.** Approximately 60,000 hectares of floodplain wetlands have been restored along the lower Danube River as a result of an international agreement signed by ministers from Bulgaria, Romania, Moldova, and Ukraine.

## Manage exploitation of freshwater species and riverine aggregates

**Science-based fisheries management.** In Malawi, the Ecosystem Approach to Fisheries management has been enshrined in legislation since the 1990s, with implementation efforts incorporating comanagement with fishery communities, a focus on sustainable harvest of high value Chambo (*Oreochromis lidole*) and breeding or nursery sanctuaries for commercial species.

**Community fisheries management.** A community protection and resource management program within oxbow lakes on the Juruá River within the Western Brazilian Amazon resulted in a thirtyfold increase in Arapaima, *Arapaima gigas*.

**Bycatch reduction.** A combination of closures and modified traps have been demonstrated to minimize platypus bycatch within commercial eel and carp fisheries in New South Wales, Australia.

**Reducing aggregates demand.** Germany recycles 87% of its waste aggregates, and in India nontoxic municipal waste is used as an aggregates substitute in road building.

**Improved regulation of riverine aggregate extraction.** In the United Kingdom, an effective regulatory regime to determine the acceptability (or otherwise) of riverine aggregate extraction has been complemented by the aggregates levy, a tax placed on sales of primary aggregates in the United Kingdom (sand, gravels and crushed rock), which has funded research to develop understanding and improve practices to minimize environmental effects of extraction.

## Prevent and control nonnative species invasions in freshwater habitats

**Identification and control of introduction pathways.** Prevention of nonnative carp species invasions in the Great Lakes (United States and Canada) has successfully used a combination of scientific risk assessments, prohibition of live fish transport, and an electrical barrier.

**Control and eradication of established invasive nonnative species.** The spread of invasive nonnative weeds such as *Mimosa pigra* was limited because of management measures implemented within the Kakadu National Park, Australia, at a cost of AUS$500,000 per year. Management measures were found to avoid an increase in *Mimosa pigra* coverage compared with areas that were not managed.

## Safeguard and restore freshwater connectivity

**System-scale infrastructure planning.** A strategic environmental assessment for hydropower planning has been undertaken in Myanmar that has recommended keeping the main stems of the Irrawaddy and Salween rivers free flowing.

**Dam reoperation and removal.** On the Penobscot River, in the United States, reoperation and removal of dams affecting 1500 kilometers of river resulted in increased populations of migratory fish species while maintaining electricity generation capacity.

**Levee repositioning.** The Room for the Rivers program in the Netherlands has stimulated large-scale levee removal and restoration of lateral connectivity along the Rhine to enhance flood storage and conveyance while also providing expanded and enhanced habitat for freshwater biodiversity.

regions, making implementation more challenging (Palazzo et al. 2019). The transboundary characteristics of many freshwater ecosystems further complicate implementation (Brown and King 2013). Even so, improved water allocation planning (Speed et al. 2013) and wiser agricultural water use (Linstead 2018) can create opportunities for progress. Shifting agricultural production to less water-stressed regions could also help (Pastor et al. 2019).

**Action 2. Improve water quality to sustain aquatic life.** Pollution impacts on freshwater biodiversity can be profound and can reflect direct toxicity or disruption to ecosystem processes. Pollution types include but are not limited to nutrients from sewage, fertilizers, or animal wastes; synthetic chemicals, such as pesticides, herbicides, heavy metals, persistent organic pollutants, and a wide range of other hazardous substances from agriculture and industry; pharmaceuticals and their metabolites from human and agricultural use; plastics across a wide size spectrum; sediments mobilized by agriculture, forestry, and mining operations; salinization caused by sea water incursion or overirrigation; and heat from industrial and power sector effluents (Reid et al. 2019).

Policy and management options include improved wastewater treatment or reuse, regulation of polluting industries, market instruments that reflect downstream pollution costs, improved agricultural practices, and nature-based solutions such as floodplain wetland restoration or riparian buffer zones (WWAP 2017).

Globally, 80% of sewage enters surface waters without adequate treatment and in Latin America, Africa, and Asia, approximately 15% of river lengths are severely polluted organically (UNEP 2016, WWAP 2017). Improved wastewater treatment should therefore be a priority for many countries. The Clean Water Act (1972) in the United States, and the European Union's Urban Wastewater Treatment Directive (1991) have helped to slow and, in some cases, reverse point–source pollution in those jurisdictions (Vaughan and Ormerod 2012). Nonpoint–source pollution from agriculture remains a problem across many regions (OECD 2017). Better farm management, often in combination with market mechanisms, can reduce pollution loads while maintaining agricultural yields (Wu and Ma 2015) but is not yet mainstream agricultural practice. In the European Union, for instance, agricultural pollution is a major reason for failure to attain "good ecological status" as required by the Water Framework Directive (European Environment Agency 2018). Improved water quality monitoring is required in many contexts, using existing guidelines (e.g., UN Environment 2017). Evidence is urgently needed on the sources, pathways, and impacts of some pollutants, including microplastics and pharmaceuticals, to inform policy and management (Reid et al. 2019).

**Action 3. Protect and restore critical habitats.** An estimated 30% of natural freshwater ecosystems have disappeared since 1970, and 87% of inland wetlands since 1700 (Davidson 2014, Dixon et al. 2016). Causes include land conversion to agriculture and reduced hydrological connectivity after dam and levee construction (Junk et al. 2013; the impacts of dams and levees on freshwater ecosystem connectivity is discussed in priority action 6 below). Climate change can alter wetland distribution and extent (Acreman et al. 2019) and affect the frequency and intensity of flood events, which then affects fluvial geomorphological processes and habitat structure (Death et al. 2015). Changes in terrestrial habitat management caused by forestry, intensive agriculture, mining, road construction, and urbanization have exacerbated pollution, sediment fluxes, and extreme flows, affecting freshwater habitats downstream (Dudgeon et al. 2006).

A variety of interventions can mitigate the impacts on freshwater biodiversity from prior degradation and reduce future risks. These include community conservation of habitats for flagship, keystone, or culturally important species; formal protected area designations; land-use planning (often linked with markets for ecosystem services); and habitat restoration programs (UN Water 2018). Strategic basin-scale planning of conservation and restoration investments can help to identify synergies and resolve trade-offs between biodiversity goals and other priorities. In doing so, it can increase social and political support for conservation and restoration and ensure that freshwater biodiversity and ecosystem services outcomes are more effective and resilient to future conditions (Speed et al. 2016). Systematic freshwater conservation planning tools, which combine stakeholder engagement with algorithm-based spatial assessment taking specific account of hydrological factors, can aid prioritization of freshwater habitats for efficient conservation and restoration investments (Reis et al. 2019).

Many freshwater ecosystems are ostensibly protected by international or national designations. For instance, the Ramsar Convention on wetlands now has 168 contracting parties worldwide who have designated 2186 Ramsar sites, covering 2.1 million square kilometers. However, formal protection has been inconsistently effective, and there is scope for wider application of lessons from successful protection efforts, such as the involvement of local communities in protected area management (Acreman et al. 2019). A lack of effective basin-scale planning and failure to address exogenous threats have also limited the biodiversity benefits of protection (Reis et al. 2017). The management of terrestrial-focused protected areas often fails to consider associated freshwater ecosystems and sometimes permits activities detrimental to their health, such as the building of dams. Protected area designations that are specifically focused on limiting threats distinct to freshwater ecosystems are relatively uncommon globally, but the US Wild and Scenic Rivers Act, Norway's National Salmon Rivers designations, and Mexico's Water Reserve policy have been used to maintain free-flowing rivers. The implementation of similar policies will be important for protecting healthy rivers in regions undergoing expansion of infrastructure construction (Moir et al. 2016).

River basin planning is enshrined widely in policies, including in places such as China, the European Union, and Brazil. Some countries, such as Uganda, have developed specific national wetland policies. Others, such as South Africa, have incorporated wetland conservation into agriculture, water, or other sectoral policies. While recognizing that nature-based solutions to water management challenges are not a panacea, the UN has recommended greater investment in them as potentially cost-effective substitutes for or augmentations to conventional built infrastructure (UN Water 2018). The UN Framework Convention on Climate Change (UNFCCC) also encourages consideration of nature-based solutions within Nationally Determined Contributions, and there is scope for these solutions to provide cobenefits in terms of climate mitigation, freshwater biodiversity recovery, and socioeconomic resilience. Nevertheless, large-scale implementation of nature-based solutions is in its infancy.

**Action 4. Manage exploitation of freshwater species and riverine aggregates.** The exploitation of living organisms and mineral substrates affects freshwater biodiversity directly through removal of individuals and their habitats and indirectly through alterations to freshwater ecosystem processes. A wide range of freshwater taxa are exploited, including plants, invertebrates (such as crabs and crayfish), fish, amphibians (such as frogs), reptiles (including turtles and their eggs), waterbirds (including geese and ducks), and mammals (including river dolphins and otters). Policy frameworks to guide such harvests are often insufficient, and enforcement is also poor, making sustainable management difficult (Cooke et al. 2016). Bycatch is a further threat, such as of river dolphins that are accidentally caught in gill nets (Iriarte and Marmontel 2013). The extraction of riverine substrates, especially sand and gravel for use in construction, is increasing rapidly (UNEP 2019). Research into biodiversity impacts is sparse, but its effects can include direct destruction of instream and riparian flora and fauna, as well as changes to fluvial geomorphological regimes with associated effects on downstream habitats (Koehnken and Rintoul 2018). (The abstraction of water resources from freshwater habitats is discussed above in relation to action 1, on implementing environmental flows.)

The 2016 Rome Declaration, convened by the Food and Agriculture Organization of the United Nations, describes the steps needed for sustainable freshwater fisheries, including improved biological assessments, science-based management, and the development of a global freshwater fisheries action plan (Taylor and Bartley 2016). Bycatch can be reduced by exploiting temporal and spatial differences between target species and bycatch distributions. Mandatory bycatch reporting can also help (Cairns et al. 2013), as can technology, such as provision of air spaces to increase survival rates of animals accidentally caught in nets (Grant et al. 2004). Solutions to riverine sand and gravel extraction can include reducing demand for construction materials (such as through avoiding overdesign in buildings) and substituting recycled materials for new concrete, supported by improved supply chain standards (UNEP 2019). Sustainable management of aggregate extraction rates, locations, and methods can be informed by analysis of geomorphological processes, and extraction can be focused on river reaches where natural accumulations of sand and gravel can accommodate removal without harming ecosystem structure and function.

Currently, lack of data and science-based management is a major concern for both freshwater fisheries (Bartley et al. 2015) and riverine aggregate extraction (UNEP 2019). The implementation of robust legal frameworks is also rare. However, there have been promising developments in fisheries policy since the Rome Declaration. These include improved planning processes in some countries (such as Cambodia) and the development of international standards for biological assessment (Bonar et al. 2017). Successful community-based fisheries management, leading to biodiversity benefits, has been documented from Thailand (Koning 2018) and Brazil (Campos-Silva and Peres 2016). Riverine aggregate extraction has been brought under improved regulatory control across parts of Europe but elsewhere, and especially in Asia, it is rapidly expanding and is often unregulated or illegal (Koehnken and Rintoul 2018).

**Action 5. Prevent and control nonnative species invasions in freshwater habitats.** Freshwater habitats are especially susceptible to INNS (Strayer 2010). The impacts of INNS on freshwater biodiversity range from behavioral shifts of native species to complete restructuring of food webs and extirpation of entire faunas (Gallardo et al. 2016). The economic costs are also significant, reaching billions of dollars in the United States alone (Pimentel et al. 2005). However, because of insufficient information, public awareness, and policy frameworks, the effects of INNS are consistently underestimated (Early et al. 2016).

Preventing introduction of INNS is the best approach to limiting impacts. Efforts have been focused on identifying major introduction pathways, such as trade in live organisms, ballast-water transfers from ships, releases of unwanted animals from aquariums, and aquaculture and horticulture escapes. Once they are established, control and eradication of INNS is normally possible only with considerable investments in physical removal, chemical treatment, or biological control. Climate change and globalization increase the risk that species currently inhabiting a limited geographic range or nonnative species that have to date only had moderate ecological or economic impacts might become more problematic. New strategies will be needed to prevent invasion and control the impacts of such species (Rahel and Olden 2008).

In a few instances, countries have taken steps to identify and prioritize INNS for action. In the United States, invasive species advisory councils bring together regulators, researchers, and stakeholders to address research, policy, and management needs related to INNS (Lodge et al. 2006). For example, efforts are continuing to prevent nonnative carp species from invading the Laurentian Great Lakes using scientific risk assessments, laws prohibiting transportation of live fish, and an innovative electrical barrier. Public or commercial hunts and harvests have been encouraged to eradicate established INNS from freshwater ecosystems, such as in the removal of nutria (*Myocastor coypus*) from the United Kingdom (Pasko et al. 2014). Although policies and strategies often target specific INNS (Early et al. 2016), the European Union recently adopted a regulation (2016/1141), which requires member states to prevent, control, or eradicate a suite of INNS, including several freshwater plant and animal species.

**Action 6. Safeguard and restore freshwater connectivity.** The flows of water, nutrients, and sediment through freshwater ecosystems are important processes regulating biodiversity. Many species depend on periodic connectivity between upstream and downstream river reaches or between river channels and floodplain habitats for their migration and reproduction (McIntyre et al. 2016). Dams and weirs fragment longitudinal (upstream to downstream) connectivity and, through flow alterations, also affect lateral (river to floodplain), vertical (surface to groundwater), and temporal (season to season) connectivity. Engineered levees and other flood management structures separate rivers from their floodplains. Grill and colleagues (2019) measured connectivity in river systems globally and found that only one-third of the world's very long rivers remain free flowing. Higher-resolution local data reveals that, in some regions, fragmentation rates are considerably higher (e.g., Jones et al. 2019).

Coherent planning for energy and water, including strategic siting of new infrastructure, can balance connectivity maintenance with hydropower generation or water storage (Opperman et al. 2019a). This can be achieved through system- or basin-scale planning and strategic environmental assessment processes that consider how potential infrastructure portfolios deliver against multiple river management objectives. Individual dams can be designed and operated to improve passage of sediment, nutrients, and biota, although, to date, such interventions have had limited efficacy (Noonan et al. 2012). Targeted removal of obsolete dams can restore longitudinal connectivity in degraded ecosystems. Removal or repositioning of levees can improve lateral connectivity while enhancing water storage or conveyance on floodplains as part of flood risk management strategies (Sayers et al. 2014).

Dams and levees continue to be built worldwide, often in the absence of adequate planning processes. One study identified approximately 3700 new hydropower dams worldwide at varying stages of the planning process (Zarfl et al. 2015). Climate impacts (such as increased flood frequency or intensity) can lead to increased pressure to build infrastructure in river basins, including dams and levees. Case studies of improved system-scale water infrastructure planning are emerging though. In Myanmar, a strategic environmental assessment identified tributaries where new hydropower dams would incur lower environmental and social risks compared to other siting options and recommended keeping the main stem Irrawaddy and Salween rivers free flowing to maintain migratory fish populations and sediment delivery to deltas (ICEM 2018). Some river-specific protection mechanisms described under priority action 3, such as the United States' Wild and Scenic Rivers Act, contain provisions to safeguard connectivity. On the Penobscot River, in the United States, a system-scale approach led to the removal of two dams and refurbishment of others, resulting in increased populations of migratory fish species (Hogg et al. 2015). Dam removal has gathered pace in recent years with more than 1600 barriers removed in the United States alone (American Rivers 2019). On rivers such as the Mississippi, the Rhine, and the Yangtze, floodplains have been reconnected with rivers through levee repositioning and reoperation of sluice gates as part of flood management system upgrades (Opperman et al. 2017, Sayers et al. 2014).

## Using the Emergency Recovery Plan to set global targets and indicators for freshwater biodiversity

If these priority actions are to be progressed widely and rapidly, a coordinated international effort will be needed to transform underlying socioeconomic drivers of freshwater biodiversity declines, stemming from food, energy, industrial and infrastructure sectors, and economic planning paradigms and to promote protection and recovery of freshwater biodiversity through improved and better integrated conservation practice and water resource management. International agreements can facilitate this coordination, galvanize national policy development, and guide investments by state and nonstate actors. As governments and other stakeholders consider a post-2020 framework for biodiversity and sustainable development, what targets and indicators can be embedded within international agreements to help bend the curve of freshwater biodiversity loss?

We have prioritised 13 existing or potential targets and indicators within the CBD and SDGs that would substantially advance implementation of the Emergency Recovery Plan (table 1a, b). The recommendations focus on CBD and the SDGs as these international agreements are due to be reviewed or revised in 2020. Other agreements will also have an important role to play, including those that specifically address freshwater conservation challenges, such as the Ramsar Convention and those primarily focused on other issues such as the UNFCCC, implementation of which could accelerate nature-based climate solutions that might also promote freshwater biodiversity recovery. Improved coordination and mutual reinforcement between all such agreements will be necessary (Bunn 2016). Involving freshwater ecosystem and biodiversity experts in discussions on targets and indicators for these global agreements will also be essential.

Several of our recommendations suggest maintaining existing elements of these agreements that are already aligned to the plan. For instance, although it does not specifically mention freshwater biodiversity, CBD Aichi target

*Table 1a. Advancing the Emergency Recovery Plan for freshwater biodiversity through international agreements: Recommendations for global targets and indicators to be incorporated into the Convention on Biological Diversity.*

| Existing target | Recommendation, including whether to maintain, amend or devise new targets or indicators | Alignment with Emergency Recovery Plan |
|---|---|---|
| CBD Aichi target 5: Habitat loss | *Amend:* Explicitly emphasize freshwater ecosystems, alongside forests; use connectivity status index (Grill et al. 2019) and an indicator of wetland extent for indicators. | Priority action 3: Protect and restore critical habitats<br>Priority action 6: Safeguard and restore freshwater connectivity |
| CBD Aichi target 6: Fisheries management | *Amend and new:* Explicitly reference inland fisheries; add new indicators and align with SDG 14.4 (see recommendations below). | Priority action 4: Manage exploitation of species and riverine aggregates |
| CBD Aichi target 8: Pollution reduction | *Amend:* Expand text and indicators to explicitly focus on the full range of pollution, including emerging contaminants such as pharmaceuticals and plastics, to emphasise addressing pollution at source rather than through end-of-pipe fixes, and to emphasise the need to retrofit waste water treatment where necessary; include freshwater eutrophication alongside coastal eutrophication in indicators. | Priority action 2: Improve water quality |
| CBD target 9: Invasive species | *Maintain and amend:* Existing target is aligned with Emergency Recovery Plan; amend wording and indicators to reflect the vulnerability and sensitivity of freshwater ecosystems to invasions. | Priority action 5: Control invasive species |
| CBD target 11: Protected areas | *Amend and new:* Define a distinct subtarget for proportion of inland waters under protection by 2030. Add new indicator of length (in kilometers) of riverine habitat that is protected and connected, including riparian habitats, headwater streams, etc. Use Connectivity Status Index (Grill et al. 2019) as an indicator to track connectivity for freshwater species. | Priority action 3: Protect and restore critical habitats<br>Priority action 6: Safeguard and restore freshwater connectivity |
| CBD target 14: Ecosystem services | *Amend:* Revise wording to emphasize the full range of services that freshwater ecosystems provide, rather than only mentioning water supply, and to emphasize the need to balance ecosystem service provision with maintenance or restoration of ecosystem structure and processes. | Priority action 1: Accelerate implementation of environmental flows<br>Priority action 3: Protect and restore critical habitats<br>Priority action 4: Manage exploitation of species and riverine aggregates<br>Priority action 6: Safeguard and restore freshwater connectivity |
| No current target | *New:* Define new targets, relevant to CBD strategic goal B (Reduce direct pressures on biodiversity), for maintaining natural flows and restoring environmental flows, and managing extraction of riverine aggregates; align these targets with, respectively, SDG 6.4 and SDG 9.4 (see below). | Priority action 1: Accelerate implementation of environmental flows |

*Note:* For simplicity and ease of reference, we have followed the existing architecture of CBD Aichi targets. If governments agree to restructure these targets and indicators in 2020, it will be important that the recommendations in the present article are integrated appropriately into the new architecture.

9 on invasive species is well aligned to priority action 5. Similarly, SDG 6 (“Clean water and sanitation”) already sets out a target for improving water quality (SDG 6.3) that links directly with priority action 2. In principle, SDG 6.4, on sustainable water withdrawals, is aligned with priority action 1 from the plan on implementing environmental flows, although there is scope within this target to improve assessment of environmental flow implementation and to encourage use of an explicit indicator of progress (FAO 2019).

A second category includes recommendations for amending or extending existing targets or indicators such that they align more strongly with the plan. For example, CBD Aichi target 11 and SDG 15.1 both aim to increase the extent of habitats that are conserved, restored or sustainably managed, and both specifically reference “inland waters.” However, these targets, and their associated indicators, are currently described in terms of the area of ecosystems to be protected. Much freshwater biodiversity is found in linear river systems and associated headwater, riparian, and floodplain habitats. A global target and associated indicator for freshwater biodiversity conservation and restoration would therefore be better framed in terms of length of riverine (and associated riparian and wetland) habitat protected and sustainably managed. This target should also acknowledge the need to protect or sustainably manage a wide range of different freshwater habitat types including—for instance, headwater streams, ponds, and other small wetland habitats that are important for biodiversity (Biggs et al. 2017). Another example of an existing target that should be extended is SDG 6.6 (protecting and restoring water-related ecosystems), which is due to expire in 2020. Extending this target to 2030 will increase coherence with other targets and encourage continued action.

A third group of recommendations concerns the need for new targets or indicators to fill major gaps. Currently, there is no recognition of alterations in water flows and levels within the CBD Aichi targets. This is a significant shortcoming, so a new target on safeguarding natural flow regimes and implementing environmental flows is needed. Extraction of riverine sand and gravel is another notable omission from both CBD and SDG targets and indicators. We recommend inclusion within SDG 9.4 (sustainable infrastructure) of an

*Table 1b. Advancing the Emergency Recovery Plan for freshwater biodiversity through international agreements: Recommendations for global targets and indicators to be incorporated into the Sustainable Development Goals.*

| | | |
|---|---|---|
| SDG 6.3: Water quality | *Maintain:* Existing target and indicators are aligned with Emergency Recovery Plan, as long as the definition of "ambient water quality" in indicator 6.3.2 incorporates the full range of pollution, and its sources, affecting freshwater ecosystems. | Priority action 2: Improve water quality |
| SDG 6.4: Sustainable water withdrawals | *Maintain and new:* Existing target is aligned with Emergency Recovery Plan. A new indicator is needed on the proportion of water bodies with environmental flows implemented. | Priority action 1: Accelerate implementation of environmental flows |
| SDG 6.6: Water-related ecosystems | *Amend:* Extend target timeline to 2030 to encourage continued effort; improve indicator 6.6.1 so that it tracks the extent of only natural inland water ecosystems, i.e., excluding artificial water bodies such as reservoirs; strengthen links with SDG 15 by explicit cross-reference to indicator 15.1.2 (proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas). | Priority action 3: Protect and restore critical habitats |
| SDG 9.4: Sustainable infrastructure | *Amend and new:* Incorporate an emphasis on green infrastructure or nature-based solutions alongside engineered infrastructure. Include new indicator of sustainability of sand and gravel sources used in concrete for construction | Priority action 3: Protect and restore critical habitats<br>Priority action 4: Manage exploitation of species and riverine aggregates<br>Priority action 6: Safeguard and restore freshwater connectivity |
| SDG 14.4: Overfishing | *Amend and new:* Extend target to cover all aquatic ecosystems, not just marine. Extend timeline to 2030 to encourage continued effort; include new indicator(s) to track the status of inland fisheries—for example, proportion of fish stocks within biologically sustainable levels within inland waters. | Priority action 4: Manage exploitation of species and riverine aggregates |
| SDG 15.1: Terrestrial and inland freshwater ecosystems | *Amend:* Strengthen links with SDG 6 by explicit cross-reference to indicators 6.3.2 (water quality), SDG 6.4.2 (water stress) and 6.6.1 (extent of water-related ecosystems, amended as above). | Priority action 1: Accelerate implementation of environmental flows<br>Priority action 3: Protect and restore critical habitats |

*Note:* For simplicity and ease of reference, we have followed the existing architecture of SDGs. If governments agree to restructure these targets and indicators in 2020, it will be important that the recommendations in the present article are integrated appropriately into the new architecture.

indicator on the proportion of construction materials that are made from sustainably sourced aggregates and cross-referencing to a new CBD target. This target should also include explicit reference to the role of nature-based solutions as potential alternatives to engineered infrastructure. Freshwater fisheries too are poorly served by current targets and indicators. SDG 14 includes targets for regulation of overfishing (SDG 14.4), but this goal only covers marine fisheries even though wild caught freshwater fish provide critical protein for hundreds of millions of people (Funge-Smith 2018). Therefore, we recommend addition of a specific indicator on freshwater fisheries and reframing of this target to cover all aquatic habitats.

## From international agreements to implementation: Roles for national and international actors and the research community

Bending the curve for freshwater biodiversity ultimately hinges on the extent to which effective policy and management interventions, as illustrated in box 1, can be replicated or adapted worldwide. International agreements can stimulate such replication, as we have discussed. However, national and local state and nonstate actors must play the central roles in defining context-specific portfolios of measures that address synergistic threats to freshwater biodiversity. Transparent decision-making, coherent target setting and planning processes, and the use of appropriate regulatory and financial mechanisms will all be necessary to underpin development and implementation of measures. A systemic approach to stakeholder engagement and dialogue will be needed, involving multiple stakeholders and a broad range of skills and disciplines to ensure a coherent approach to policy and planning for freshwater ecosystem management (Tickner et al. 2017). Active involvement of and leadership by those most affected by management of freshwater habitats and biodiversity will be essential, including local communities, women, young people, and indigenous groups. The presence of "policy entrepreneurs" (Huitema et al. 2011) or "champions" (O'Keeffe 2018), who recognize opportunities for restoration and galvanize coordinated action, can accelerate progress. Depending on the context, these roles can be played by politicians, business leaders, community representatives, nongovernmental organization (NGO) experts, media personalities, or schoolchildren. To nurture future champions, educators will need to reflect the challenges facing freshwater (and other) biodiversity in school curricula, and universities should incorporate training on strategy, communications, and stakeholder engagement into technical degree programs on conservation, water resource management, and related disciplines.

The mitigation hierarchy—which is focused sequentially on avoiding, minimizing, restoring, and, finally, offsetting impacts of economic development on ecosystems and biodiversity—might be a useful tool as these actors develop context-specific portfolios of measures (Arlidge et al. 2018). In many contexts, a high priority for freshwater biodiversity conservation should be the avoidance of in situ or exogenous threats, such as dams, that would adversely affect the few remaining freshwater ecosystems that are largely unaffected by human development, such as free-flowing rivers (Grill et al. 2019). Where threats already exist or are unavoidable, minimizing their impacts will be the next priority. For instance, ensuring that new dams are sited such that their impacts on biodiversity hotspots or basin-scale connectivity are minimized and designed and operated to facilitate environmental flows will be essential. For ecosystems that are already degraded, it will be important to harness “hot moments” (Jay O’Keeffe, Rhodes University, 1 December 2018), such as environmental disasters or shifting political priorities, that can trigger ecosystem restoration opportunities such as dam removal or pollution reduction (Speed et al. 2016). Although controversial and open to misapplication (Simonds et al. 2019), offsetting of the impacts of development might improve the prospects for biodiversity conservation beyond status quo efforts in some situations, for instance through removal of existing or impending threats to one freshwater ecosystem as compensation for infrastructure development on another within the same jurisdiction.

Multilateral organizations, international NGOs and the private sector can contribute by supporting local and national actors to establish appropriate enabling conditions, including improved ecosystem governance, enhanced options assessments, more sustainable finance flows, capacity building for water resource and wetland managers, and better monitoring tools (Harwood et al. 2018). For example, the International Finance Corporation, a multilateral institution, funded a strategic environmental assessment in which options were compared for hydropower development in Myanmar, as was described above. In Mexico, the World Wildlife Fund, an international NGO, worked closely with government agencies to develop the science that underpinned water allocations for hundreds of rivers through environmental water reserves (Barrios et al. 2015, Opperman et al. 2019b). And the private sector, in the form of multinational textile companies and retailers, played an important role in the establishment of the Better Cotton Initiative (http://stories.bettercotton.com/timeline/index.html), which has promoted improved farming practices in cotton-growing countries such as Pakistan, helping to reduce use of polluting pesticides and fertilizers (Zulfiqar and Bopal 2016).

The research community also has an important role to play. To support international targets and to help governments and others to gauge the extent to which action is leading to recovery of freshwater ecosystems, an improved suite of indicators of global freshwater biodiversity status is urgently needed. These indicators should be relevant (i.e., they should provide information salient to each of the six actions in the plan), repeatable and affordable, scientifically robust and statistically comparable, scalable (e.g., to countries or river basins, as well as to the globe), and sufficiently sensitive to show the impacts of different policy measures. Research on indicators can build on and strengthen existing efforts, including the Living Planet Index (McRae et al. 2017), the Red List Index (Butchart et al. 2007), the Wetland Extent Trends index (Darrah et al. 2019), and the Connectivity Status Index for rivers (Grill et al. 2019). Priorities include more comprehensive, higher-resolution data on river flows and water levels, water infrastructure, water quality, and exploitation and extraction of freshwater species and materials, drawing on in situ and remote sensing technologies. There remain substantial gaps in data on freshwater taxa (e.g., approximately 30% of freshwater mollusk species and 40% of decapod crustaceans are currently classified as data deficient) and for some freshwater ecosystems (e.g., many of those in sub-Saharan Africa). Modeling studies are also needed to aid design of conservation and restoration portfolios by identifying potential trade-offs and synergies among, for example, land management, water resources, climate, and freshwater biodiversity outcomes (Davis et al. 2015, Byers et al. 2018) and by exploring the relative costs and benefits of different driver-focused and ecosystem management interventions.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, whose remit includes evidence assessment and policy advice to inform international agreements, can support the Emergency Recovery Plan by highlighting the need for improved monitoring of freshwater biodiversity, synthesizing data and encouraging appropriate government responses to monitoring results, including, potentially, through a global thematic assessment of freshwater biodiversity (Doug Beard, 17 July 2019). The Intergovernmental Panel on Climate Change can also contribute by comprehensively reviewing the scientific evidence of the likely biodiversity implications of interactions between climate change, water resources, and freshwater ecosystems. Given the opportunity, the freshwater science and biodiversity research community can play an important role by engaging with such assessments and by providing data and expertise.

## Conclusions

The Emergency Recovery Plan presented in this article is rooted in practical experience across developed and emerging economies; all the actions we highlight have already been implemented somewhere in the world. The challenge now is to transition from ad hoc freshwater conservation and restoration successes to a strategic approach that achieves results at a far larger scale.

Conservation and restoration measures will only be effective at this scale if they are based on an understanding of the processes that underpin freshwater ecosystems and biodiversity and the distinct threats to them, such as flow modification and connectivity loss. Simplistically regarding freshwater habitats as a subset of forests or grasslands obscures those distinct threats and precludes effective action. Conversely, carefully designed portfolios of conservation and restoration actions addressing the most critical direct threats and drivers can lead to rapid improvements in the condition of freshwater ecosystems.

The development of a post-2020 global biodiversity framework provides a once in a generation opportunity to promote such improvements at scale and to avoid the irreversible losses of species and habitats that would arise from continuation of business-as-usual approaches to conservation, water resource management, and policy. Given the dramatic declines in freshwater biodiversity, which far exceed those observed in terrestrial or marine ecosystems, policymakers must ensure that the priority actions we have defined are central to the post-2020 framework. The recommendations we have provided for adjustments to relevant targets and indicators should guide their decisions. Those in the conservation science and practitioner communities who influence policymakers have an important role to play in conveying this message.

Bending the curve of biodiversity loss will be a long-term process. For the flora and fauna in our rivers, lakes, and inland wetlands, adoption of an improved set of targets and indicators in 2020, and investment in their implementation in the coming decade, are urgent and critical first steps to recovery.

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