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

David Tickner*, Chief Freshwater Adviser, WWF-UK, Living Planet Centre, Woking, GU21 4LL, UK, dtickner@wwf.org.uk

Jeff Opperman, Lead Freshwater Scientist, WWF, Global Science Team, Chagrin Falls, Ohio, USA, jeff.opperman@wwf.org

Robin Abell, Freshwater Lead, Conservation International, 2011 Crystal Drive, Suite 500, Arlington VA 22201, USA, rabell@conservation.org

Mike Acreman, Hydro-ecology Consulting, 58 Wantage Road, Wallingford, Oxfordshire, OX100LY, GB, hydro_ecology_consulting@yahoo.co.uk

Angela H. Arthington, Emeritus Professor, Australian Rivers Institute, Griffith University, Nathan, Queensland Australia 4111, a.arthington@griffith.edu.au

Stuart E. Bunn, Director, Australian Rivers Institute, Griffith University, Nathan, Queensland Australia 4111, s.bunn@griffith.edu.au

Steven J. Cooke, Canada Research Professor of Environmental Science and Biology, Fish Ecology and Conservation Physiology Laboratory, Carleton University, Ottawa, ON, K1S 5B6 Canada, StevenCooke@cunet.carleton.ca

James Dalton, Director – Global Water Programme, International Union for the Conservation of Nature (IUCN), Rue Mauverney 28 1196 Gland, Switzerland, james.dalton@iucn.org

Will Darwall, Head – IUCN Freshwater Biodiversity Unit, Global Species Programme, International Union for the Conservation of Nature (IUCN), Cambridge, CB2 3QZ, UK, William.DARWALL@iucn.org

Gavin Edwards, Global Coordinator – Nature 2020, WWF International, Living Planet Centre, Woking, GU21 4LL, UK, gedwards@wwfint.org

Ian Harrison, IUCN-SSC Freshwater Conservation Committee/Conservation International, 2011 Crystal Drive, Suite 500, Arlington VA 22201, USA, iharrison@conservation.org

Kathy Hughes, Freshwater Specialist, WWF-UK, Living Planet Centre, Woking, GU21 4LL, UK, KHughes@wwf.org.uk

Tim Jones, DJEnvironmental, Harpers Mill, Berrynarbor, Ilfracombe EX34 9TB, UK, tim.jones@djenvironmental.com

David Leclère, Research Scholar, International Institute for Applied System Analysis (IIASA), Schlossplatz 1. 2361 Laxenburg, Austria, leclere@iiasa.ac.at

Abigail J. Lynch, Research Fish Biologist, National Climate Adaptation Science Center, U.S. Geological Survey, 12201 Sunrise Valley Drive, Reston, VA 20192, USA, ajlync@gmail.com

Philip Leonard, Deputy Director, Freshwater Practice, WWF International, Living Planet Centre, Woking, GU21 4LL, UK, pleonard@wwfint.org

Michael E. McClain, Professor of Ecohydrology, IHE Delft Institute for Water Education, 38 Delft, The Netherlands, and Delft University of Technology, Delft, The Netherlands, m.mcclain@un-ihe.org

Dean Muruven, Policy Lead, Freshwater Practice, WWF International, Driebergseweg 10, 3708 JB Zeist, Netherlands, dmuruven@wwfint.org

Julian D. Olden, School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington USA, olden@uw.edu

Steve Ormerod, Professor of Ecology, Cardiff School of Biosciences/Water Research Institute, University of Cardiff, Sir Martin Evans Building, Cardiff, CF10 3AX, Ormerod@cardiff.ac.uk

Rebecca E. Tharme, Director, Riverfutures, Cressbrook, Derbyshire, SK17 8SX, UK, rebeccatharme@riverfutures.com

Michele Thieme, Lead Freshwater Scientist, WWF-US, 1250 24th St., NW, Washington, DC, USA, Michele.Thieme@wwfus.org

Klement Tockner, Liebniz Institute of Freshwater Ecology and Inland Fisheries, and Institute of Biology, Freie Universität Berlin, Berlin, Germany (present address: Austrian Science Fund, FWF, 1090 Vienna, Austria), Klement.Tockner@fwf.ac.at

Mark Wright, Director of Science, WWF-UK, Living Planet Centre, Woking, GU21 4LL, UK, mwright@wwf.org.uk

Lucy Young, Science Adviser, WWF-UK, Living Planet Centre, Woking, GU21 4LL, UK, lyoung@wwf.org.uk

## Abstract

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 co-ordinated action to reverse this decline is lacking. We present an Emergency Recovery Plan to "bend the curve" of freshwater biodiversity loss. Priorities for action include: 1) accelerating implementation of environmental flows, 2) improving water quality, 3) protecting and restoring critical habitats, 4) managing exploitation of freshwater species and riverine aggregates, 5) preventing and controlling non-native species invasions, and 6) safeguarding and restoring river connectivity. We recommend revised targets and indicators for the Convention on Biological Diversity and the Sustainable Development Goals, and investment in enabling conditions at national, river basin and local scales.

## Keywords

River restoration, wetlands, freshwater conservation, Sustainable Development Goals, Convention on Biological Diversity

## Introduction

Humans have caused widespread planetary change, ushering in a new geological era, the Anthropocene. 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), the Sustainable Development Goals (SDGs) and the UN Framework Convention on Climate Change (UNFCCC). 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 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 mammal, 5,700 dragonflies, 250 turtles (Balian et al. 2008), 17,800 fishes (Fricke et al. 2019), and 1,600 crabs (N. Cumberlidge, pers comm). 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, management of freshwater ecosystems has disregarded the fact that they consist of important habitats, instead prioritizing a narrow range of services for economic benefit. 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). Of the 29,500 freshwater dependent species so far assessed for the IUCN Red List, 27% are threatened with extinction and 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 threatened (IUCN 2019). Populations of freshwater megafauna, defined as animals that reach a body mass of 30kg, 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, wider 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 increasing protected area coverage (e.g. Visconti et al. 2019). While 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.

Here, 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 post-disaster recovery situations, and we have deliberately used the word "emergency" to convey the urgency with which conservationists, water managers, stakeholders and decision-makers 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 1). Five of these focus on the major causes of freshwater biodiversity loss described by Dudgeon et al. (2006): flow alteration; pollution; habitat degradation and loss; overexploitation of species; and invasive non-native species. 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). These priorities actions are inter-related; action 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 socio-economic terms. As we outline in Table 1, each priority action has been implemented successfully in one or more situations across the globe, providing proof of concept and lessons that can inform scaling-up of actions. Below, for each priority action, we briefly review the problem, likely policy and management solutions, and the current implementation status of these solutions.

Action 1: Accelerate Implementation of Environmental Flows

*The problem.* Water management for power generation, 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 linkages between hydrological regimes and the life histories of freshwater species (Bunn and Arthington 2002) and thus contribute substantially to losses of freshwater biodiversity. Climate change exacerbates flow alteration in many situations (Döll and Bunn 2014).

*Potential solutions:* Maintaining or restoring ecologically important attributes of hydrological regimes improves biodiversity outcomes (Bunn and Arthington 2002, Olden et al. 2014). The science and practice of environmental flow (e-flow) assessment enables identification and quantification of these attributes. A sophisticated methodological toolbox now exists for developing e-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 e-flow assessment tools consider desired socio-economic 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).

*Implementation status.* E-flows have been incorporated into policies in many jurisdictions (Le Quesne et al. 2010). For instance, the European Union has recommended their inclusion in river basin management plans required by the EU Water Framework Directive (CIS 2015); the nine Nile Basin countries have agreed a common e-flows assessment strategy (NBI 2016); and China has integrated e-flows into Environmental Impact Assessment laws (Chen and Wu 2019). Examples of 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 regions making implementation more challenging (Palazzo et al. 2019). 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).

<u>Action 2. Improve Water Quality to Sustain Aquatic Life</u>

*The problem.* Pollution impacts on freshwater biodiversity can be profound and can reflect direct toxicity and/or disruption to ecosystem processes. Pollution types include, but are not limited to: 1) nutrients from sewage, fertilisers or animal wastes; 2) synthetic chemicals such as pesticides, herbicides, heavy metals, persistent organic pollutants (POPs) and a wide range of other hazardous substances from agriculture and industry; 3) pharmaceuticals and their metabolites from human and agricultural use; 4) plastics across a wide size spectrum; 5) sediments mobilized by agriculture, forestry and mining operations; 6) salinization caused by sea water incursion or over-irrigation; and 7) heat from industrial and power sector effluents (Reid et al. 2019).

*Potential solutions.* Policy and management options include wastewater treatment and/or re-use, 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).

*Implementation status.* 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. In the USA and Europe, the Clean Water Act 1972 and the EU Urban Wastewater Treatment Directive have helped to slow and, in some cases, reverse point-source pollution (Vaughan and Ormerod 2012). Non point-source pollution remains a problem across all regions. 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 EU, 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, utilising existing guidelines (e.g. UN Environment 2017). Evidence is urgently needed on sources, pathways and impacts of some pollutants, including microplastics and pharmaceuticals, to inform policy (Reid et al. 2019).

Action 3. Protect and Restore Critical Habitats

*The problem.* 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). Climate change can also alter wetland habitat distribution and extent (Acreman *et al*., 2009). Changes in terrestrial habitat management caused by forestry, intensive agriculture, mining, road construction and urbanisation have exacerbated pollution, sediment fluxes and extreme flows, affecting freshwater habitats downstream (Dudgeon et al. 2006).

*Potential solutions.* A variety of interventions can mitigate impacts on freshwater biodiversity from prior degradation and reduce future risks, including formal protected area designations, land-use planning (often linked with markets for ecosystem services) and habitat restoration programs (UN Water 2018). Strategic 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 conservation planning tools, which combine stakeholder engagement with algorithm-based spatial assessment, can aid prioritisation of habitats for efficient conservation and restoration investments (Reis et al. 2019).

*Implementation status.* 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 2,186 Ramsar Sites, covering 2.1 million km$^2$. Formal protection has been only patchily effective though and lessons from successful protection efforts – for instance, on involving local communities in protected area management – should be applied more widely (Acreman et al, in rev). Management of terrestrial-oriented protected areas often does not consider freshwater ecosystems, and sometimes permits activities detrimental to their health, such as the building of dams. 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). Some countries, such as Uganda, have developed national wetland policies. Others, such as South Africa, have incorporated wetland conservation into agriculture, water or other sectoral policies. River basin planning is enshrined widely in policies, including in places such as China, the EU and Brazil. The UN has recommended investment in nature-based solutions to water management challenges as cost-effective substitutes for, or augmentations to, conventional built infrastructure (UN Water 2018), although large-scale implementation is in its infancy.

Action 4. Manage Exploitation of Freshwater Species and Riverine Aggregates

*The problem.* Exploitation of living organisms and mineral substrates impacts 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), birds (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 which are accidentally caught in gill nets (Iriarte and Marmontel 2013). Extraction of riverine substrates, especially sand and gravel for use in construction, is increasing very rapidly (UNEP 2019). Research into biodiversity impacts is sparse, but effects can include direct destruction of instream and riparian flora and fauna, and changes to fluvial geomorphological regimes with associated effects on downstream habitats (Koehnken and Rintoul 2018). (Abstraction of water from freshwater habitats is discussed above in relation to Action 1, on implementing environmental flows.)

*Potential solutions.* The 2016 Rome Declaration, convened by the UN Food and Agriculture Organisation, describes steps needed for sustainable freshwater fisheries, including improved biological assessments, science-based management and 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. 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 over-design in buildings), substituting recycled materials for new concrete, and better management of extraction rates, locations and methods, including through improved supply chain standards (UNEP 2019).

*Implementation status.* 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). 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 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 Non-native Species Invasions in Freshwater Habitats

*The problem.* The impacts of invasive non-native species (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 US alone (Pimentel et al. 2005). However, due to insufficient information, public awareness and policy frameworks, the effects of INNS are consistently underestimated (Early et al. 2016).

*Potential solutions.* Preventing introduction of INNS is the best approach to limiting impacts. Efforts have 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 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 of trade necessitate new strategies to prevent and control INNS that, currently, inhabit limited geographic ranges or have only moderate ecological or economic impacts (Rahel and Olden 2008).

*Implementation status.* In a few instances, countries have taken steps to identify and prioritize INNS for action. In the USA, 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 non-native 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 UK (Pasko et al. 2014). Although policies and strategies often target specific INNS (Early et al. 2016), the European Union (EU) 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 problem.* 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 flood defences separate rivers from their floodplains. Grill et al. (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 can be considerably higher (Jones et al. 2019).

*Potential solutions.* Strategic siting of new infrastructure can balance connectivity maintenance with hydropower generation or water storage (Opperman et al. 2015). 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 and/or conveyance on floodplains as part of flood risk management strategies (Sayers et al. 2014).

*Implementation status.* Dams and levees continue to be built worldwide, often in the absence of adequate planning processes. One study identified approximately 3,700 large hydropower dams that might yet be built across the globe (Zarfl et al. 2015). Case studies of 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 mainstem Irrawaddy and Salween rivers free-flowing to maintain migratory fish populations and sediment delivery to deltas (IFC, 2018). On the Penobscot River, USA, 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 1,600 barriers removed in the USA alone (American Rivers, 2019). On rivers such as the Mississippi, Rhine and the Yangtze, floodplains have been reconnected with rivers through levee repositioning and re-operation of sluice gates as part of flood management system upgrades (Opperman et al. 2017, Sayers et al. 2014).

## Using the Emergency Recovery Plan to Develop Global Targets and Indicators for Freshwater Biodiversity

If these priority actions are to be progressed widely and rapidly, a co-ordinated international effort will be needed to: 1) Transform underlying socio-economic drivers of freshwater biodiversity declines, stemming from food, energy, industrial and infrastructure sectors, and economic planning paradigms; and 2) Promote recovery of freshwater biodiversity through improved conservation practice and better management of water resources (including improved integration of water and nature conservation policies). International agreements can facilitate this co-ordination, galvanize national policy development and guide investments by state and non-state 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 thirteen existing or potential targets and indicators within the CBD and SDGs that can most substantially advance implementation of, the Emergency Recovery Plan (Table 2). The recommendations focus on CBD and the SDGs as these international agreements are due to be reviewed and 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 important (Bunn 2016).

Several of our recommendations suggest *maintaining existing elements* of these agreements which are already aligned to the Plan. For instance, while it does not specifically mention freshwater biodiversity, CBD Aichi Target 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) which 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 how e-flows are being implemented and to encourage use of an explicit indicator on this aspect (FAO, 2019).

A second category includes recommendations for *amending or extending existing targets and/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 be explicit about the need to protect or sustainably manage a wide range of different habitat types including, for instance, headwater streams and ponds which are important for biodiversity (Biggs et al. 2017). Another example is SDG 6.6 (protecting and restoring water-related ecosystems), which is due to expire in 2020. This target should be extended to 2030 to ensure coherence with other relevant targets and to 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 implementing e-flows is needed. Riverine sand and gravel extraction is another notable omission from both CBD and SDG targets and indicators. We recommend inclusion within SDG 9.4 (sustainable infrastructure) of an indicator on the proportion of construction materials that are made from sustainably sourced aggregates and cross-referencing to a new CBD target. Freshwater fisheries are also 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). Thus, we recommend addition of a specific indicator on freshwater fisheries and reframing of this target to cover all aquatic habitats.

To support these 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 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, 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. Given limitations of current data, the development of an improved suite of indicators on freshwater environments and biodiversity should be a priority for the scientific and donor community. This can build on, and strengthen, existing indicators including the Living Planet Index (McRae et al. 2017), the Red List Index (Butchart et al. 2007), and the Connectivity Status Index for rivers (Grill et al. 2019). Priorities for effort include accurate, high resolution data on hydrology, water infrastructure, water quality and exploitation and extraction of freshwater species and materials. There remain substantial gaps in data on freshwater taxa (e.g. approximately 30% of freshwater mollusc 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). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), whose remit includes evidence assessment and policy advice to inform international agreements, can play a stronger role in supporting monitoring of freshwater biodiversity, including through a global thematic assessment of freshwater biodiversity and its contributions to people (D. Beard, USGS, pers. comm.). The Intergovernmental Panel on Climate Change (IPCC) can also assist by comprehensively reviewing the scientific evidence of the likely interactions between climate change and freshwater ecosystems.

## From International Agreements to Implementation

Bending the curve for freshwater biodiversity ultimately hinges on the extent to which effective policy and management interventions (Table 1) can be replicated or adapted across national, basin and local scales. International agreements must stimulate such replication, as discussed. Multilateral organisations, international

NGOs and the private sector can contribute by supporting local and national actors to establish appropriate enabling conditions, including improved ecosystem governance, more sustainable finance flows and better monitoring tools.

Context-specific portfolios of measures will be needed to address synergistic threats to freshwater biodiversity. Research and modelling can aid portfolio design by identifying potential trade-offs and synergies between, for example, land management, water resources, climate and biodiversity outcomes (Byers et al. 2018) and by exploring the relative impacts of driver-focused and ecosystem management interventions. Given the scale of the global challenge and likely limits on funding, freshwater ecosystems which remain largely unaffected by human development, such as free-flowing rivers (Grill et al. 2019), should be high priorities for conservation investment. In these ecosystems, the emphasis should be on mitigating emerging threats, including in situ developments such as dams and exogenous threats such as upstream pollution, water use, infrastructure and invasive non-native species. For ecosystems that are already degraded, it will be important to harness "hot moments" (J. O'Keeffe, Rhodes University, pers. comm.), such as environmental disasters or shifting political priorities, that can trigger restoration opportunities (Speed et al. 2016).

Stakeholder dialogue will be an essential part of the process, and a systemic approach to engagement will normally be required, involving multiple stakeholders and a broad range of skills and disciplines (Tickner et al. 2017). The presence of "policy entrepreneurs" (Huitema et al. 2011) or "champions" (O'Keeffe 2018), who recognise hot moments and galvanise co-ordinated action, can accelerate progress. Depending on context, these roles can be played by politicians, captains of industry, community leaders, NGO representatives, media personalities or schoolchildren. To nurture future leaders, universities should incorporate training on strategy, communications and stakeholder engagement into technical degree programmes on freshwater conservation, water resource management and related disciplines.

## Conclusion

The Emergency Recovery Plan presented here should guide urgent and concerted global action for freshwater biodiversity. The Plan 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 successes to a strategic approach to recovery that achieves results at a far larger scale.

Measures will only be effective if they are based on an understanding of the processes that underpin freshwater ecosystems and the distinct threats to them, such as flow modification and connectivity loss. Simply regarding freshwater habitats as a subset of terrestrial ecosystems obscures those distinct threats and precludes effective action. Conversely, carefully designed portfolios of conservation and restoration actions addressing the most critical direct and indirect threats can stimulate 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. For freshwater biodiversity across the globe, the next decade will be critical.

## Author contributions

DT, JO and MT conceived this paper. DT and TJ led the workshop at which the scope and contents of the paper were discussed. JO, MT, RA, MA, SEB, SJC, GE, IH, KH, DL, PL, MM, JDO, SO, KT, MW and LY all participated in that workshop. Further substantive inputs on the priority actions and recommendations set out in the paper were received from AHA, JD, AJL, DM and RET. All authors helped to revise initial and final drafts of the paper.

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## Conflict of interest statement

The authors declare that they have no conflicts of interest. AJL declares that any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

## References

Abell R, Thieme ML, Revenga C, Bryer M, Kottelat M, Bogutskaya N, Coad B, Mandrak N, Balderas SC, Bussing W. 2008. Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. BioScience 58:403-414.

Acreman, M., Hughes, K., Arthington, A., Tickner, D. and Dueñas, M. (in review) Protected areas and freshwater biodiversity: lessons for effective conservation, Conservation Letters

Acreman M, Arthington AH, Colloff MJ, Couch C, Crossman ND, Dyer F, Overton I, Pollino CA, Stewardson MJ, Young W. 2014. Environmental flows for natural, hybrid, and novel riverine ecosystems in a changing world. Frontiers in Ecology and the Environment 12:466-473.

American Rivers. 2019 Map of US Dams Removed Since 1912. https://www.americanrivers.org/threats-solutions/restoring-damaged-rivers/dam-removal-map/. Accessed September 2019

Arthington AH, Bhaduri A, Bunn SE, Jackson SE, Tharme RE, Tickner D, Young B, Acreman M, Baker N, Capon S et al. 2018. The Brisbane declaration and global action agenda on environmental flows (2018). Frontiers in Environmental Science 6.

Balian E, Lévèque C, Segers H. 2008. Freshwater Animal Diversity Assessment, ed. Martens, K., Vol. 595: Springer, The Netherlands.

Bartley D, De Graaf G, Valbo-Jørgensen J, Marmulla G. 2015. Inland capture fisheries: status and data issues. Fisheries Management and Ecology 22:71-77.

Biggs J, Von Fumetti S, Kelly-Quinn M. 2017. The importance of small waterbodies for biodiversity and ecosystem services: implications for policy makers. Hydrobiologia 793:3-39.

Bonar SA, Mercado-Silva N, Hubert WA, Beard Jr TD, Dave G, Kubečka J, Graeb BD, Lester NP, Porath M, Winfield IJ. 2017. Standard methods for sampling freshwater fishes: opportunities for international collaboration. Fisheries 42:150-156.

Bunn SE. 2016. Grand challenge for the future of freshwater ecosystems. Frontiers in Environmental Science 4:21.

Bunn SE, Arthington AH. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30:492-507.

Butchart SH, Akçakaya HR, Chanson J, Baillie JE, Collen B, Quader S, Turner WR, Amin R, Stuart SN, Hilton-Taylor C. 2007. Improvements to the red list index. PLoS One 2:e140.

Byers E, Gidden M, Leclère D, Balkovic J, Burek P, Ebi K, Greve P, Grey D, Havlik P, Hillers A. 2018. Global exposure and vulnerability to multi-sector development and climate change hotspots. Environmental Research Letters 13:055012.

Cairns NA, Stoot LJ, Blouin-Demers G, Cooke SJ. 2013. Refinement of bycatch reduction devices to exclude freshwater turtles from commercial fishing nets. Endangered Species Research 22:251-261.

Campos-Silva JV, Peres CA. 2016. Community-based management induces rapid recovery of a high-value tropical freshwater fishery. Scientific reports 6:34745.

Ceballos G, Ehrlich PR, Dirzo R. 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proceedings of the National Academy of Sciences 114:E6089-E6096.

Chen A, Wu M. 2019. Managing for Sustainability: The Development of Environmental Flows Implementation in China. Water 11:433.

CIS W. 2015. Guidance Document No 31: Ecological Flows in the Implementation of the Water Framework Directive. Technical Report.

Cooke SJ, Allison EH, Beard TD, Arlinghaus R, Arthington AH, Bartley DM, Cowx IG, Fuentevilla C, Leonard NJ, Lorenzen K. 2016. On the sustainability of inland fisheries: finding a future for the forgotten. Ambio 45:753-764.

Davidson NC. 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. Marine and Freshwater Research 65:934-941.

Dixon M, Loh J, Davidson N, Beltrame C, Freeman R, Walpole M. 2016. Tracking global change in ecosystem area: the Wetland Extent Trends index. Biological Conservation 193:27-35.

Döll P, Bunn SE. 2014. The impact of climate change on freshwater ecosystems due to altered river flow regimes. Climate change:143-146.

Dudgeon D, et al. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biol Rev Camb Philos Soc 81:163-182.

Early R, Bradley BA, Dukes JS, Lawler JJ, Olden JD, Blumenthal DM, Gonzalez P, Grosholz ED, Ibañez I, Miller LP. 2016. Global threats from invasive alien species in the twenty-first century and national response capacities. Nature Communications 7:12485.

European Environment Agency, 2018, Ecological status of surface water bodies, https://www.eea.europa.eu/themes/water/european-waters/water-quality-and-water-assessment/water-assessments/ecological-status-of-surface-water-bodies, accessed 1st July 2019

FAO. 2019. Incorporating environmental flows into “water stress” indicator 6.4.2 - Guidelines for a minimum standard method for global reporting. Rome. 32 pp.

Fricke R, Eschmeyer W, van der Laan R. 2019. Catalog of fishes: genera, species, references: California Academy of Sciences. Internet resource (http://researcharchive. calacademy. org/research/ichthyology/catalog/SpeciesByFamily. asp), accessed January 19:2019.

Funge-Smith S. 2018. Review of the state of the world fishery resources: Inland fisheries. FAO Fisheries and Aquaculture Circular.

Gallardo B, Clavero M, Sánchez MI, Vilà M. 2016. Global ecological impacts of invasive species in aquatic ecosystems. Global Change Biology 22:151-163.

Gardner R, Finlayson C. 2018. Global wetland outlook: state of the World’s wetlands and their services to people. The Ramsar Convention Secretariat: Gland, Switzerland.

Grant T, Lowry M, Pease B, Walford T, Graham K. 2004. Reducing the by-catch of platypuses (Ornithorhynchus anatinus) in commercial and recreational fishing gear in New South Wales. Pages 259. Proceedings of the Linnean Society of New South Wales: Linnean Society of New South Wales.

Grill G, et al. 2019. Mapping the world's free-flowing rivers. Nature 569:215-221.

Grooten M, Almond R. 2018. Living Planet Report–2018: Aiming Higher. WWF, Gland, Switzerland.

Harrison I, Abell R, Darwall W, Thieme ML, Tickner D, Timboe I. 2018. The freshwater biodiversity crisis. Science 362:1369-1369.

Harwood A, Johnson S, Richter B, Locke A, Yu X, Tickner D. 2017. Listen to the river: lessons from a global review of environmental flow success stories. WWF-UK, Woking, UK.

He F, Zarfl C, Bremerich V, David JN, Hogan Z, Kalinkat G, Tockner K, Jähnig SC. 2019. The global decline of freshwater megafauna. Global Change Biology.

Hogg RS, Coghlan Jr SM, Zydlewski J, Gardner C. 2015. Fish community response to a small-stream dam removal in a maine coastal river tributary. Transactions of the American Fisheries Society 144:467-479.

Huitema D, Lebel L, Meijerink S. 2011. The strategies of policy entrepreneurs in water transitions around the world. Water Policy 13:717-733.

IFC 2018. Strategic environmental assessment of the Myanmar Hydropower Sector, IFC, Washington DC

Iriarte V, Marmontel M. 2013. River dolphin (Inia geoffrensis, Sotalia fluviatilis) mortality events attributed to artisanal fisheries in the Western Brazilian Amazon. Aquatic Mammals 39:116.

IUCN 2019. The IUCN Red List of Threatened Species. Version 2019-1. http://www.iucnredlist.org. Downloaded on 5 June 2019.

Jones J, Börger L, Tummers J, Jones P, Lucas M, Kerr J, Kemp P, Bizzi S, Consuegra S, Marcello L. 2019. A comprehensive assessment of stream fragmentation in Great Britain. Science of The Total Environment 673:756-762.

Junk WJ, An S, Finlayson C, Gopal B, Květ J, Mitchell SA, Mitsch WJ, Robarts RD. 2013. Current state of knowledge regarding the world's wetlands and their future under global climate change: a synthesis. Aquatic Sciences 75:151-167.

Koehnken L, Rintoul M. 2018. Impacts of Sand Mining on Ecosystem Structure, Process and Biodiversity in Rivers. Gland, Switzerland. Report no.

Kok MT, Alkemade R, Bakkenes M, van Eerdt M, Janse J, Mandryk M, Kram T, Lazarova T, Meijer J, van Oorschot M. 2018. Pathways for agriculture and forestry to contribute to terrestrial biodiversity conservation: A global scenario-study. Biological Conservation 221:137-150.

Koning AA. 2018. Riverine Reserves: The Conservation Benefits of Spatial Protection for Rivers in the Context of Environmental Change. The University of Wisconsin-Madison.

Le Quesne T, Kendy E, Weston D. 2010. The Implementation Challenge: Taking stock of government policies to protect and restore environmental flows. Godalming, UK: WWF & The Nature Conservancy. Report no.

Linstead CL. 2018. The contribution of improvements in irrigation efficiency to environmental flows. Frontiers in Environmental Science 6:48.

Lodge DM, Williams S, MacIsaac HJ, Hayes KR, Leung B, Reichard S, Mack RN, Moyle PB, Smith M, Andow DA. 2006. Biological invasions: recommendations for US policy and management. Ecological Applications 16:2035-2054.

Lynch AJ, et al. 2016. The social, economic, and environmental importance of inland fish and fisheries. Environmental Reviews 24:115-121.

Mace GM, Barrett M, Burgess ND, Cornell SE, Freeman R, Grooten M, Purvis A. 2018. Aiming higher to bend the curve of biodiversity loss. Nature Sustainability 1:448.

McIntyre PB, Reidy Liermann C, Childress E, Hamann EJ, Hogan JD, Januchowski-Hartley SR, Koning AA, Neeson TM, Oele DL, Pracheil BM. 2016. Conservation of migratory fishes in freshwater ecosystems. Cambridge University Press: Cambridge.

McRae L, Deinet S, Freeman R. 2017. The diversity-weighted living planet index: controlling for taxonomic bias in a global biodiversity indicator. PLoS One 12:e0169156.

NBI (Nile Basin Initiative), 2016. Strategy for Management of Environmental Flows in the Nile Basin. Nile Basin Initiative Secretariat. 17p.

Noonan MJ, Grant JW, Jackson CD. 2012. A quantitative assessment of fish passage efficiency. Fish and Fisheries 13:450-464.

O'Keeffe JH. 2018. A perspective on training methods aimed at building local capacity for the assessment and implementation of environmental flows in rivers. Frontiers in Environmental Science 6:125.

Olden JD, Konrad CP, Melis TS, Kennard MJ, Freeman MC, Mims MC, Bray EN, Gido KB, Hemphill NP, Lytle DA. 2014. Are large-scale flow experiments informing the science and management of freshwater ecosystems? Frontiers in Ecology and the Environment 12:176-185.

Opperman J, Grill G, Hartmann J. 2015. The Power of Rivers: Finding balance between energy and conservation in hydropower development. The Nature Conservancy. Washington DC.

Opperman J, Moyle PB, Larsen EW, Florsheim JL, Manfree AD. 2017. Floodplains: Processes and management for ecosystem services. Univ of California Press.

Palazzo A, Valin HJP, Batka M, Havlík P. 2019. Investment Needs for Irrigation Infrastructure along Different Socioeconomic Pathways: The World Bank.

Pasko S, Goldberg J, MacNeil C, Campbell M. 2014. Review of harvest incentives to control invasive species. Management of Biological Invasions 5:263-277.

Pastor A, Palazzo A, Havlik P, Biemans H, Wada Y, Obersteiner M, Kabat P, Ludwig F. 2019. The global nexus of food–trade–water sustaining environmental flows by 2050. Nature Sustainability 2:499.

Pimentel D, Zuniga R, Morrison D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52:273-288.

Poff NL, Tharme RE, Arthington AH. 2017. Evolution of environmental flows assessment science, principles, and methodologies. Pages 203-236. Water for the environment, Elsevier.

Rahel FJ, Olden JD. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22:521-533.

Reid AJ, Carlson AK, Creed IF, Eliason EJ, Gell PA, Johnson PT, Kidd KA, MacCormack TJ, Olden JD, Ormerod SJ. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biological Reviews.

Reis V, Hermoso V, Hamilton SK, Bunn SE, Linke S. 2019. Conservation planning for river-wetland mosaics: A flexible spatial approach to integrate floodplain and upstream catchment connectivity. Biological Conservation 236:356-365.

Reis V, Hermoso V, Hamilton SK, Ward D, Fluet-Chouinard E, Lehner B, Linke S. 2017. A global assessment of inland wetland conservation status. BioScience 67:523-533.

Sayers P, Galloway G, Penning-Rowsell E, Yuanyuan L, Fuxin S, Yiwei C, Kang W, Le Quesne T, Wang L, Guan Y. 2014. Strategic flood management: ten 'golden rules' to guide a sound approach. International Journal of River Basin Management:1-15.

Speed R, Tickner D, Naiman R, Gang L, Sayers P, Yu W, Yuanyuan L, Houjian H, Jianting C, Lili Y. 2016. River restoration: A strategic approach to planning and management. UNESCO Publishing.

Speed R, Yuanyuan L, Zhiwei Z, Le Quesne T, Pegram G. 2013. Basin water allocation planning: principles, procedures and approaches for basin allocation planning. UNESCO. Paris.

Strayer DL, Dudgeon D. 2010. Freshwater biodiversity conservation: recent progress and future challenges. Journal of the North American Benthological Society 29:344-358.

Taylor WW, Bartley DM. 2016. Call to Action–The "Rome Declaration": Ten Steps to Responsible Inland Fisheries. Fisheries 41:269-269.

Tickner D, Parker H, Oates NE, Moncrieff CR, Ludi E, Acreman M. 2017. Managing Rivers for Multiple Benefits–A Coherent Approach to Research, Policy and Planning. Frontiers in Environmental Science 5:4.

UN Water. 2018. 2018 UN World Water Development Report, Nature-based Solutions for Water.

UNEP. 2016. Snapshot of the World's Water Quality: Towards a Global Assessment. Nairobi: United Nations Environment Programme.

UNEP. 2019. Sand and Sustainability: Finding new solutions for environmental governance of global sand resources. Geneva, Switzerland: GRID-Geneva, United Nations Environment Programme. Report no.

UN Environment 2017. A Framework for Freshwater Ecosystem Management. Volume 2: Technical guide for classification and target-setting.

Vaughan IP, Ormerod SJ. 2012. Large-scale, long-term trends in B ritish river macroinvertebrates. Global Change Biology 18:2184-2194.

Visconti P, Butchart SH, Brooks TM, Langhammer PF, Marnewick D, Vergara S, Yanosky A, Watson JE. 2019. Protected area targets post-2020. Science 364:239-241.

Wu W, Ma B. 2015. Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. Science of The Total Environment 512:415-427.

WWAP U. 2017. Wastewater: the Untapped Resource, The United Nations World Water Development Report: UNESCO, Paris.

Zarfl C, Lumsdon AE, Berlekamp J, Tydecks L, Tockner K. 2015. A global boom in hydropower dam construction. Aquatic Sciences 77:161-170.

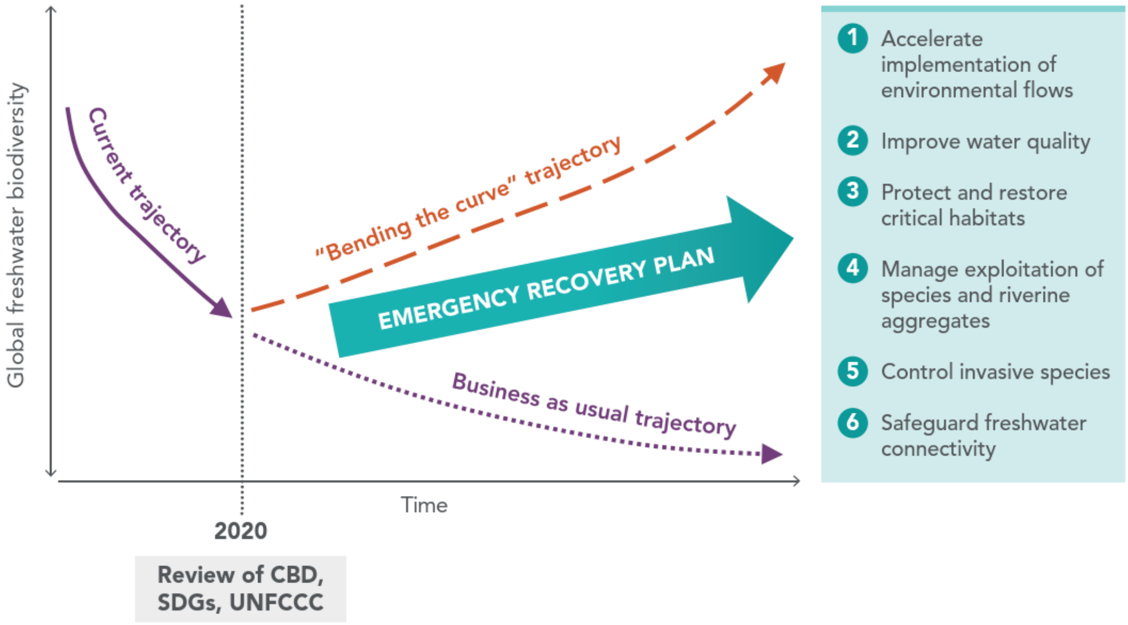


**Figure 1: The Emergency Recovery Plan for Freshwater Biodiversity: Six priorities for global action to bend the curve of freshwater biodiversity loss that should be reflected in the post-2020 biodiversity framework**

| 1. **Accelerate implementation of environmental flows** |
|---|
| **River basin planning**: E-flows have been incorporated into water legislation in South Africa and implemented through legally-mandated Catchment Management Agencies, e.g. on the Crocodile River<br><br>**Water allocation**: Mexico's Water Reserves initiative sets sustainable water allocation limits for 189 rivers across the country, taking account of e-flows<br><br>**Infrastructure design and operation**: E-flows to benefit downstream fisheries are now part of the operational regime of the Three Gorges Dam, China |
| 2. **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<br><br>**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.<br><br>**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.<br><br>**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<br><br>**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 |
| 3. **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 ha Bita River basin (a sub-basin 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<br><br>**Land-use planning/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<br><br>**Habitat restoration**: Approximately 60,000 ha 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 |
| 4. **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 co-management with fishery communities, a focus on sustainable harvest of high-value Chambo (*Oreochromis lidole*) and breeding/nursery sanctuaries for commercial species. |

| |
|---|
| **Community fisheries management**: A community protection and resource management programme within oxbow lakes on the Juruá River within the Western Brazilian Amazon resulted in a thirty-fold increase in Arapaima, *Arapaima gigas* |
| **Bycatch reduction**: A combination of closures and modified traps have been demonstrated to minimise 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 non-toxic municipal waste is used as an aggregates substitute in road-building |
| **Improved regulation of riverine aggregate extraction**: In the UK, 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 UK (sand, gravels & crushed rock), which has funded research to develop understanding and improve practices to minimise environmental effects of extraction. |
| 5. **Prevent and control non-native species invasions in freshwater habitats** |
| **Identification and control of introduction pathways**: Prevention of non-native carp species invasions in the Great Lakes (US 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 non-native species**: The spread of invasive non-native weeds such as *Mimosa pigra* was limited due to 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 of 2.7% or higher (58 km2) compared to areas that were not managed. |
| 6. **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 mainstems of the Irrawaddy and Salween Rivers free-flowing |
| **Dam re-operation and removal**: On the Penobscot River, USA, re-operation and removal of dams along 1,500km of river resulted in increased populations of 11 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 |

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

| Existing target | Recommendation, including whether to maintain, amend or devise new targets and/or indicators | Alignment with Emergency Recovery Plan |
| --- | --- | --- |
| | **Convention on Biological Diversity targets and indicators** | |
| CBD Aichi Target 5: Habitat loss | *Amend*: i) Explicitly emphasize freshwater ecosystems, alongside forests; ii) 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/New*: i) Explicitly reference inland fisheries; ii) 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*: i) Expand text and indicators to explicitly focus attention on the full range of pollution, including emerging contaminants such as pharmaceuticals and plastics, and to emphasise addressing pollution at source rather than through end-of-pipe fixes; ii) Include freshwater eutrophication alongside coastal eutrophication in indicators. | Priority Action 2. Improve water quality |
| CBD Target 9: Invasive species | *Maintain/Amend*: i) Existing target is aligned with Emergency Recovery Plan; ii) Amend wording and indicators to reflect the particular vulnerability and sensitivity of freshwater ecosystems to invasions. | Priority Action 5. Control invasive species |
| CBD Target 11: Protected areas | *Amend/New*: i) Define a distinct sub-target for proportion of Inland Waters under protection by 2030. ii) Add new indicator of length (km) of riverine habitat that is protected and connected, including riparian habitats, headwater streams, etc. iii) 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 and/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 i) maintaining and restoring e-flows, and ii) managing extraction of riverine substrates, as distinct and essential measures to bend the curve on freshwater | Priority Action 1. Accelerate implementation of environmental flows |

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| | biodiversity loss; align these targets with, respectively, SDG 6.4 and SDG 9.4 (see below). | |
| | **Sustainable Development Goal targets and indicators** | |
| 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/New*: Existing target is aligned with Emergency Recovery Plan, but a new indicator is needed on the proportion of water bodies with e-flows implemented. | Priority Action 1. Accelerate implementation of environmental flows |
| SDG 6.6: Water-related ecosystems | *Amend*: i) Extend target timeline to 2030 to encourage continued effort; ii) 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; iii) 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 | *New*: Include new indicator of sustainability of sand and gravel sources used in concrete for construction | Priority Action 4. Manage exploitation of species and riverine aggregates |
| SDG 14.4: Overfishing | *Amend/New*: i) Extend target to cover all aquatic ecosystems, not just marine and extend timeline to 2030 to encourage continued effort; ii) Include new indicator(s) to track separately the status of inland fisheries, e.g. 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 |

**Table 2. 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 and Sustainable Development Goals. Note: For simplicity and ease of reference, we have followed the existing architecture of CBD Aichi Targets and SDGs. If governments agree to restructure these targets and indicators in 2020, it will be important that the recommendations here are integrated appropriately into the new architecture.**