Received: 21 April 2020 | Revised: 8 September 2020 | Accepted: 26 September 2020

DOI: 10.1111/conl.12771

Conservation Letters
A journal of the Society for Conservation Biology
Open Access

WILEY

REVIEW

Safeguarding freshwater life beyond 2020: Recommendations for the new global biodiversity framework from the European experience

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Funding information
Leibniz-Gemeinschaft, Grant/Award Number: J45/2018; Bundesministerium für Bildung und Forschung, Grant/Award Numbers: 01LC1501G1, 01LN1320A; Fulbright Association, Grant/Award Number: Fulbright Early Career Scholar Award; Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Grant/Award Number: UID/AMB/50017/2019; Natural Environment Research Council, Grant/Award Number: NE/N006437/1; Akademie Věd České Republiky, Grant/Award Number: J. E. Purkyně Fellowship; Ministerio de Ciencia e Innovación, Grant/Award Number: RYC-2013-13979; Belgian Federal Science Policy Office, Grant/Award Number: BR/175/A1/ORC; European Union's Horizon 2020 research and innovation programme, Grant/Award Number: 642317

Abstract
Plans are currently being drafted for the next decade of action on biodiversity—both the post-2020 Global Biodiversity Framework of the Convention on Biological Diversity (CBD) and Biodiversity Strategy of the European Union (EU). Freshwater biodiversity is disproportionately threatened and underprioritized relative to the marine and terrestrial biota, despite supporting a richness of species and ecosystems with their own intrinsic value and providing multiple essential ecosystem services. Future policies and strategies must have a greater focus on the unique ecology of freshwater life and its multiple threats, and now is a critical time to reflect on how this may be achieved. We identify priority topics including environmental flows, water quality, invasive species, integrated water resources management, strategic conservation planning, and emerging technologies for freshwater ecosystem monitoring. We synthesize these topics with decades of first-hand experience and recent literature into 14 special recommendations for global freshwater biodiversity conservation based on the successes and setbacks of European policy, management, and research. Applying and following these recommendations will inform and enhance the ability of global and European post-2020 biodiversity agreements to halt and reverse the rapid global decline of freshwater biodiversity.

KEYWORDS
climate change, conservation, ecosystem services, rivers, sustainable development goals, water resources, wetlands

1 | INTRODUCTION

Freshwater biodiversity is one of the most diverse and imperiled parts of the biosphere (Reid et al., 2019; Strayer & Dudgeon, 2010; Vörösmarty et al., 2010). Freshwater ecosystems face numerous anthropogenic threats including invasive alien species (IAS), the modification, degradation, and fragmentation of habitats, overexploitation, climate change, and pollution. These ecosystems also depend on the quality, quantity, and timing of fresh water, an increasingly scarce resource (Shumilova, Tockner, Thieme, Koska, & Zarfl, 2018; van Rees, Cañizares, Garcia, & Reed, 2019). Despite the diversity and severity of threats, and strong ties to human wellbeing, freshwater ecosystems are consistently underrepresented in biodiversity research and conservation (Mazor et al., 2018; Tydecks, Jeschke, Wolf, Singer, & Tockner, 2018). Concerted research and policy actions are needed at a global scale to safeguard freshwater life and its associated ecosystem services, requiring a coherent and far-reaching framework (Darwall et al., 2018; Tickner et al., 2020). To date, however, there exists no such specific guidance for addressing the freshwater biodiversity crisis, and actions to halt this crisis have been inadequate (Harrison et al., 2018; IPBES, 2019).

The Convention on Biological Diversity (CBD), the primary international agreement for conserving biodiversity, is an important means by which such actions could be implemented. In decision X/10, the CBD (2010) adopted the Strategic Plan for Biodiversity 2011–2020. Its targets have not been met, and global biodiversity declines continue (IPBES, 2019). In decision 14/34 (CBD, 2019) parties began drafting a Global Biodiversity Framework (GBF) for post-2020 actions to achieve its 2050 vision of "Living in Harmony with Nature" (CBD, 2020). This framework must be adequate for tackling the ongoing freshwater biodiversity crisis.

There is an interlinked, parallel process in Europe to adopt a new Biodiversity Strategy (hereafter "Strategy") post-2020 (European Commission, 2019). This Strategy reflects the commitment by the European Union (EU) to support the CBD, so these initiatives share many considerations and priorities. They also benefit similarly from guidance from the scientific community. The EU consists of 27 Member States representing diverse economic, cultural, and linguistic backgrounds and is the second-largest economy in the world, necessitating effective legislation at multiple scales. European freshwater biodiversity covers a wide range of biotypes and climatic zones, from Mediterranean to Arctic, and is affected by all major anthropogenic threats to freshwater systems. European directives are transposed and separately implemented by different member states, but set shared objectives and vision. EU-scale research, environmental policies, and case studies are thus powerfully informative for inter- or multi-national biodiversity strategies in other regions. The EU freshwater conservation experience, including successes and failures, provides an abundance of material with which to inform global strategies and responses.

Tickner et al. (2020) outlined six priority actions for slowing and reversing freshwater biodiversity declines, including recommendations for their incorporation into major international agreements. Here, we build upon the foundation of their important contribution with freshwater biodiversity-specific recommendations to guide the new GBF and EU Strategy. Our work combines an extensive literature review and decades of research, management, and policy experience in European freshwater conservation in eleven countries. This review complements and supports Tickner et al. (2020) while addressing new issues and highlighting specific approaches for implementation. We organize these recommendations according to the structure used in planning the GBF (CBD, 2018, 2019): (1) outcome-oriented elements, (2) enabling conditions and means of implementation, (3) planning and accountability modalities, and (4) cross-cutting approaches and issues (Figures 1 and 2). Our goal is to inform both agreements from a freshwater perspective and provide global recommendations based on lessons and examples from Europe. We begin with a brief review of relevant policy mechanisms functioning at the global and European scales (Figure 3) to highlight key current national and international policies that are necessary for understanding and implementing these recommendations. A more comprehensive history of freshwater conservation in Europe is available elsewhere (e.g., Aubin & Varone 2004).

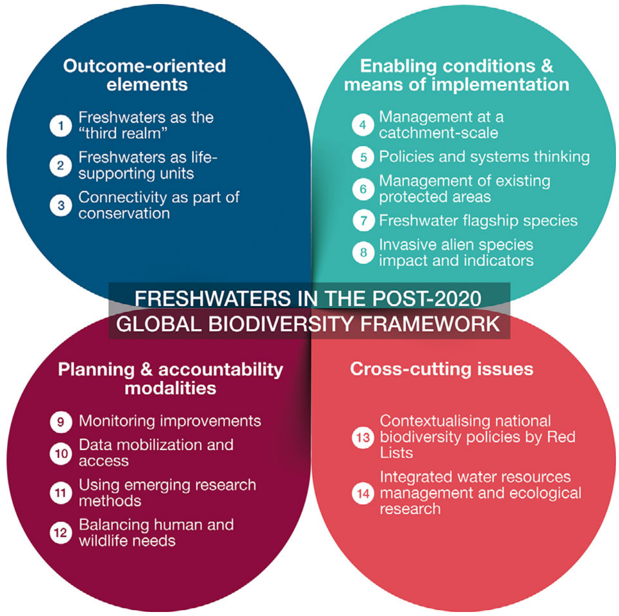

FIGURE 1 Summary of the 14 Special Recommendations organized around the four clusters of the GBF planning process

2 | POLICY BACKGROUND—THE GLOBAL FRESHWATER CONSERVATION CONTEXT

The Ramsar Convention on wetlands (1971), the first coordinated global-scale political effort in freshwater biodiversity conservation, focused on sustainable management or "wise use" of wetland habitats (including coral reefs and estuaries). Its list of wetlands of international importance covers 13–18% of the global wetland area (Davidson & Finlayson, 2018), but outside of these areas, wetland loss is rapid and ongoing (IPBES, 2019; Ramsar, 2018).

The CBD (adopted in 1993; Figure 3) provided international impetus for biodiversity conservation, although it groups freshwaters with the terrestrial realm. The CBD Strategic Plan for Biodiversity 2011–2020 included 20 Aichi Biodiversity Targets. Among the most relevant to freshwater are Target 11, the conservation of terrestrial and inland waters and marine areas, Target 5, halving the rate of habitat loss, Target 12, no extinctions, Target 8, the reduction of pollution pressures, and Target 9, the prevention, eradication and control of IAS.

The Sustainable Development Agenda for 2030 integrates seventeen Sustainable Development Goals (SDGs; Figure 3), adopted in 2015 by the United Nations. These guide national and international efforts in biodiversity conservation and sustainable development. Target 6.6 (part of SDG6 "Clean Water and Sanitation") explicitly mentions the protection and restoration of aquatic ecosystems,while SDG 15 "Life on Land" only implicitly includes inland waters, and SDG 14 "Life below water" exclusively addresses marine ecosystems (Darwall et al., 2018).

3 | POLICY BACKGROUND—THE EUROPEAN FRESHWATER CONSERVATION CONTEXT

Four directives are especially relevant to freshwater ecosystems in the EU. The Birds (2009/147/EC) and Habitats

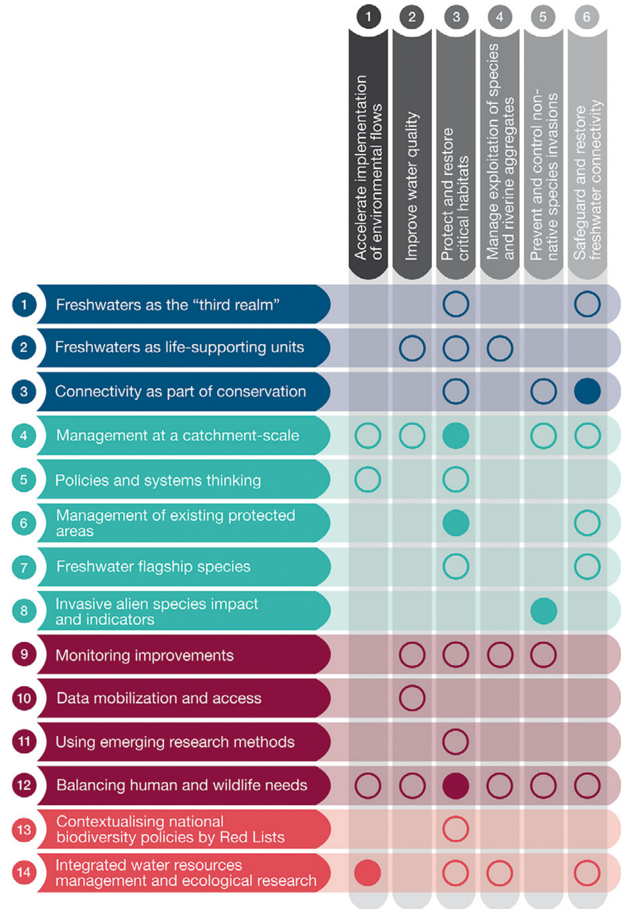

FIGURE 2 Matrix diagram illustrating where the 14 Special Recommendations expand upon or complement Tickner et al. (2020)'s priority actions. Filled circles indicate parallel coverage, and open circles indicate where SRs provide means of implementation for priority actions, as these topics were not specifically covered by the priority actions

(HD; 92/43/EC; Figure 3) Directives are the EU's two main policies for nature conservation. Areas protected under these two Directives form an ecological network, Natura 2000, which covers 18% of the EU's land area and river network (and ~8% of its marine territory; its coverage of nonriparian freshwater habitats has not been quantified). Its main purpose is to maintain—or restore—Europe's most valuable and threatened habitats and species to a favorable conservation status. The European Red List of Threatened Species (European Commission, 2010) provides assessments and listings of conservation status for European species.

The Water Framework Directive (WFD, Directive 2000/60/EC; Figure 3) establishes an EU-wide basis for integrated water resource management (IWRM) with the overall aim of "Good Ecological Status" for all water bodies (based upon biological and chemical quality, water quantity and connectivity). The WFD also includes a separate designation and goals for Highly Modified Water Bodies (HMWB), which are those irreversibly modified for human needs. These are held to attain "Good Ecological Potential," a condition when all possible mitigating measures are implemented, only tolerating necessary modifications, without jeopardizing the goals of the HD (Hering et al., 2010). The WFD incorporates earlier directives like the Urban Waste Water Directive (91/271/EC) and extends these in establishing a multidimensional assessment of ecological status, and requiring assessment and planning organized around River Basins. It is thus a pioneering legislation and has catalyzed radical change in the assessment and management of freshwaters (Carvalho et al., 2019), while stimulating globally relevant research at the science-policy interface (Reyjol et al., 2014). The Floods Directive (Directive 2007/60/EC) was adopted to reduce and manage risks to society caused by flooding.

Importantly, the WFD calls for the implementation of environmental flows (e-flows), the practice of using flow–response relationships and societal water management goals to outline sustainable scenarios for river flow regimes (Acreman & Ferguson, 2010; Poff, Tharme, & Arthington, 2017). A pan-European e-flows group has developed guidance that links directly to the HD (European Commission, 2015a, b). E-flows are an important and essential approach to any future strategies in freshwater biodiversity conservation and are covered by Tickner et al. (2020).

The WFD may not perfectly encompass all challenges for freshwater biodiversity: it notably lacks reference to wetlands or ecosystem services (Hödl, 2018), and may not adequately protect and restore smaller water bodies (Riley et al., 2018). However, some subsequent policymaking has complemented its provisions. In particular, the Eel Regulation (1100/2007) obliges Member States to make management plans with structural measures to make rivers passable and improve habitats. Freshwater biodiversity has also benefited from other policies, for example, the Large Combustion Plants Directive (2001/80/EC) has significantly reduced pollutant loading on surface waters. Notably, the WFD implicitly considers IAS impacts within an ecological status assessment process (Boon, Clarke, & Copp, 2020). The IAS Regulation (1143/2014) sets common standards for preventing their introduction and spread, with key provisions on (1) preventing introductions by managing priority pathways, (2) early detection and rapid response, and (3) control to contain and manage established species. The WFD itself and complementary policies illustrate the potential of a holistic approach to planning and updating policymaking for freshwater.

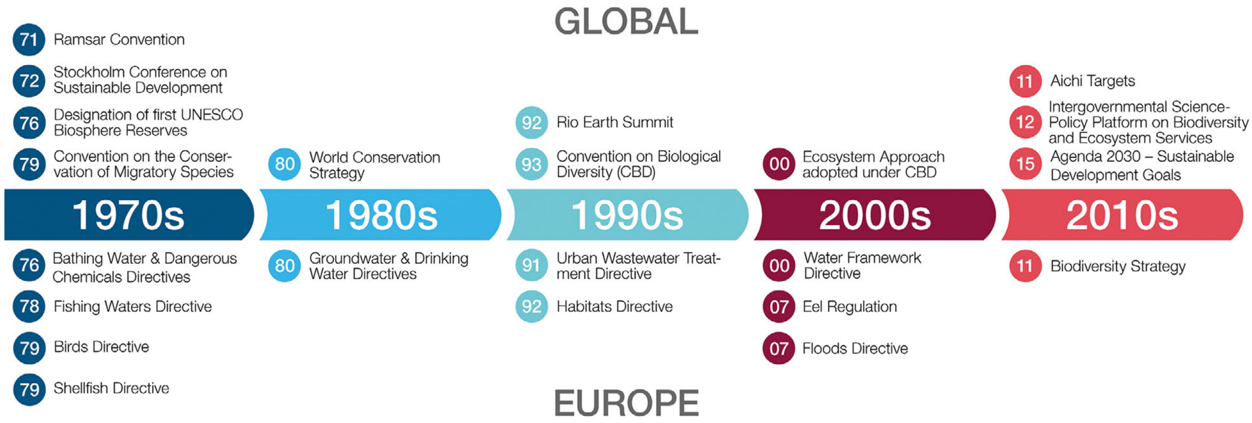

FIGURE 3 Selected international conventions (above) and European policies (below) that are directly relevant to freshwater biodiversity conservation and restoration

4 | SPECIAL RECOMMENDATIONS FOR FRESHWATER BIODIVERSITY POST-2020

Against this policy background and considering the connection between the EU Strategy and the new GBF, we present 14 special recommendations (SRs; Figure 1) for future strategies to safeguard freshwater biodiversity.

4.1 | Outcome-oriented elements (vision, mission, goals, and targets)

4.1.1 | SR1: Freshwater should be considered a true ecological "third realm" that deserves legal and scientific prominence in future frameworks and strategies

The unique threats, critical ecosystem services, and idiosyncratic ecology of freshwater systems (connectivity and fragmentation across scales, high levels of endemism; Dudgeon et al., 2006) make them a distinct ecological realm whose explicit recognition has important consequences for applied conservation. There is a need for separate policies on freshwater ecosystems, which are too often lumped in with terrestrial habitats (as nonmarine) or marine environments (as aquatic). Such policies should recognize the characteristics of freshwater ecosystems that distinguish them from other habitats, but also their connections to habitats in the surrounding landscape and atmosphere (SR4). Future conservation agreements should explicitly acknowledge freshwater ecosystems as a separate realm with distinct value, ecological dynamics, and conservation needs. For example, targets specific to freshwater ecosystems could be added to SDG 13, 14, or 15. Improved delineation of protected freshwater areas, accounting for hydrological and biotic connections, would further ensure that both terrestrial and aquatic species are protected, and pressures reduced (SR3 & SR4). An equivalent target to the representative protected fraction of terrestrial ecoregions should be created for freshwater (Abell et al., 2008), and key areas for freshwater biodiversity should be designated, protected, and restored to the extent possible (e.g. Dinerstein et al., 2019).

Within the freshwater realm, new strategies should address the bias in research, management, and policy principally focused on rivers and lakes, largely excluding other freshwater habitats (Oertli, Céréghino, Hull, & Miracle, 2009; Williams et al., 2004). Ponds (small lentic waterbodies), springs (crenic or groundwater habitats), and urban and artificial wetlands are largely missing from most conservation legislation (Bolpagni et al., 2019; Cantonati, Füreder, Gerecke, Jüttner, & Cox, 2012; Hill et al., 2018; Oertli, 2018). These overlooked habitats deliver critical ecosystem services, often to communities that heavily depend on them, and support a substantial proportion of extant freshwater biodiversity (Clifford & Heffernan, 2018; Kløve et al., 2011; Oertli & Parris, 2019). The separate designation of HMWB's in Europe's WFD represents a workable exemplar of a policy structure that could accommodate urban and farmland water bodies and other freshwater habitats that differ substantially from those given preferential study and attention.

4.1.2 | SR2: Freshwater ecosystems should be viewed and recognized as life-supporting units that provide vital ecosystem functions and services in addition to their intrinsic value

To protect freshwater biodiversity, national and international agreements must recognize the essential services provided by freshwater ecosystems to human societies, especially nature-based solutions and multiple uses by marginalized peoples (Boelee et al., 2017; Grizzetti, Lanzanova, Liquete, Reynaud, & Cardoso, 2016; IPBES, 2019; MEA, 2005). In Europe, the MARS project examined practical methodologies for evaluating ecosystem services to support WFD river basin planning (Grizzetti et al., 2019), a good example of explicit, large-scale accounting needed to holistically value these ecosystems. Additionally, many freshwater services, including those pertaining to water supply, cross political borders (Munia, Guillaume, Mirumachi, Wada, & Kummu, 2018). Management strategies must thus account for the different spatiotemporal scales at which ecosystem services reach users, to ensure resource protection and reduce potential conflicts between policies or stakeholders (Islam & Repella, 2015; SRs 5 & 12). Communicating freshwaters' diverse and important ecosystem services will strengthen the rationale for protecting freshwater life. Wetlands in urban and agricultural settings often make strong contributions to these services, and should thus be explicitly recognized (Oertli & Parris, 2019). The services provided by freshwater ecosystems may also be the focus of incentivizing conservation through strategies like Payment for Ecosystem Services schemes (Venkatachalam & Balooni, 2018). An important caveat is that focusing on instrumental value via ecosystem services is only one rationale for protecting biodiversity, and intrinsic value is also an important conservation ethic. This is particularly true where biodiversity features make no significant contribution to ecosystem services.

4.1.3 | SR3: Connectivity across multiple spatiotemporal scales and hydrological dimensions is a vital part of conserving and managing freshwater ecosystems

The hydrological dynamics (i.e., network topology, connectivity/fragmentation, seasonality) of freshwater systems across scales (e.g., landscape or drainage), time, and dimensions (e.g., longitudinal or upstream–downstream, lateral or channel–floodplain, vertical or hyporheic interactions) are essential for maintaining freshwater biodiversity (Tickner et al., 2020, Action 6). In Europe, past initiatives related to flooding and renewable energy have relied heavily on dams and channelization, likely driving declines in many freshwater taxa (e.g., sturgeons, Jarić, Riepe, & Gessner, 2018; freshwater mussels, Cosgrove & Hastie, 2001) but a recent push to remove obsolete dams or make them passable (e.g. www.damremoval.eu) shows increasing awareness of this problem. Strategic planning frameworks that take connectivity into account can help balance competing interests around connectivity issues (Seliger et al., 2016; see SRs 5 & 12).

Anthropogenic changes in connectivity also facilitate IAS spread and biotic homogenization (Strecker & Brittain, 2017). In Europe, this is illustrated by range extensions of aquatic species following the opening of interbasin canals (e.g., Wiesner, 2005). In some situations, barriers to dispersal may help isolate IAS from vulnerable native species, thus slowing the spread of diseases and parasites and reducing extinction risk, although conflicting with measures to increase connectivity for other ecological goals (Manenti et al., 2019). Future policies should explicitly consider the nuanced and complex relationship between biological and hydrological connectivity and societal water management.

4.2 | Enabling conditions and means of implementation

4.2.1 | SR4: Freshwater ecosystems should be managed and delineated at the catchment scale, considering their drainage networks, catchment areas, and bordering ecotones

Freshwater ecosystems do not function in isolation from their terrestrial and atmospheric context, but receive environmental pressures from the surrounding landscape (Dudgeon et al., 2006). Considering ecological connectivity and the need for multihabitat availability, cross-realm (*sensu* Creech, McClure, & van Rees, 2017) protected areas, and catchment-scale management are high priority. Extending Tickner et al.'s (2020) Action 3 we emphasize that freshwater biodiversity conservation must account for the complex interplay between multiple stressors acting across spatiotemporal scales and between freshwater habitats within the catchment (Finlayson, Arthington, & Pittock, 2018). Recognizing that interventions can affect freshwater biodiversity elsewhere in a catchment necessitates a strategic approach to catchment management. SR's 12 and 14 (and Tickner et al., 2020's Priority Action 1 on e-flows) expand this management paradigm to include societal variables.

We highlight Abell, Allan, and Lehner (2007)'s recommendations to integrate the protection of freshwater biodiversity focal areas with catchment management, extending protection from riparian buffer zones to upstream areas. This multihabitat approach contrasts conventional protection of freshwater ecosystems by explicitly managing the hydrological and ecological links among freshwater habitats and their corresponding uplands (Finlayson et al., 2018). This could be augmented by combining Freshwater Ecoregions (Abell et al., 2008) with land-use management at large catchment scales (Paukert et al., 2017). Future policy should acknowledge the need to reduce external pressures arising from the degradation of connected ecosystems (Schinegger, Trautwein, Melcher, & Schmutz, 2012; SR5).

The WFD's emphasis on catchment-scale management offers an exemple for other integrated biodiversity policies (Hering et al., 2010). Member States are obliged to design River Basin Management Plans that analyze the issues reducing ecological quality and to propose Programmes of Measures according to the WFD. This legislation unites national, previously fragmented policy goals related to water, and has greatly stimulated international cooperation on water management. This has led to some successes, but there is substantial room for improvement, particularly in upscaling the WFD's harmonized approach (Moe, Couture, Haande, Lyche Solheim, & Jackson-Blake, 2019).

4.2.2 | SR5: Global conservation strategies should make use of systems-thinking to properly navigate the strong societal and economic importance of freshwaters

The interactions of freshwater ecosystems with hydrology, other ecological realms, and society lead to well-known characteristics of complexity, including nonlinearity, historical character, and feedback loops (van Rees, Garcia, & Cañizares, 2019). To manage this uncertainty and avoid excluding potentially important allochthonous variables (van Rees & Reed, 2015), future policies affecting freshwater should adopt a systems-thinking approach (*sensu* Zhang et al., 2018). These should view freshwater habitats as complex systems embedded in and connected with other socioecological systems and focus on monitoring essential parameters to understand system functioning across scales (Levin et al., 2013; Waylen et al., 2019).

Different environmental goals are not always aligned; for example, decreasing carbon emissions via hydropower development can conflict with riparian restoration (Seliger et al., 2016). Explicit recognition of trade-offs is necessary, so decision-makers must pay close attention to potential conflicts between legislation protecting freshwater-dependent biodiversity and that which affects other resources. In Europe, the nature directives have occasionally conflicted with the WFD; for example, when managing water bodies that support waterfowl (European Commission, 2011). Challenges more often arise with policies that are not specifically environmental, such as the Common Agricultural Policy (CAP), which tends to favor intensive agricultural practices that lead to increased nitrogen loading and/or water abstraction (Jansson, Höglind, Andersen, Hasler, & Gustafsson, 2019). Future policies for freshwater biodiversity should therefore acknowledge and accommodate potential conflicts arising from the strong dependence of human wellbeing on freshwater resources. The challenge of integrating and acknowledging biodiversity conservation in other policy arenas (e.g., agriculture, energy, economic development) is thus a topic where European experience offers useful insights. Identifying potential synergies between the WFD, EU Biodiversity Strategy, climate policy (e.g., SR6), and/or floods policy (Waylen, Blackstock, Tindale, & Juárez-Bourke, 2019) would be particularly effective at the EU scale.

4.2.3 | SR6: Restoration, improved management, and enforcement within existing freshwater protected areas could provide simultaneous climate and conservation benefits

Designating new protected areas can be politically and economically challenging, especially in densely populated areas like Europe (Maiorano et al., 2015). This is exacerbated for freshwater ecosystems, where protection can run counter to societal needs for freshwater (van Rees & Reed, 2015); worldwide, water abstraction and poor enforcement in protected areas are known to reduce conservation value (Acreman, Hughes, Arthington, Tickner, & Dueñas, 2019). The pervasive global degradation of wetland habitats and difficulty of protecting new areas means that restoration and improved management within currently protected areas could yield substantial conservation gains. In the EU, the geographic ranges of many threatened species overlap with the Natura 2000 network, Ramsar sites, and other protected areas, and could benefit from intensified and integrative management within them (Hermoso, Morán-Ordóñez, Canessa, & Brotons, 2019). Restoration is also important and effective in nonprotected areas like human-dominated landscapes, which make up a greater portion of the Earth's land surface (Hettiarachchi, Morrison, & McAlpine, 2015; Sayer et al., 2012).

Restoring (rewetting) Europe's peatlands is expected to provide carbon sequestration (Joosten, 2016), while restoration of other types of wetlands can reduce intensifying flood and drought cycles under climate change (Moomaw et al., 2018). Restoration of riparian woodlands can also provide carbon sequestration benefits (Thomas, Griffiths, & Ormerod, 2016). Wetland restoration may simultaneously provide biodiversity benefits (Benson, Carberry, & Langen, 2018; Funk et al., 2020; Turunen, Markkula, Rajakallio, & Aroviita, 2019), although the degree of success of such efforts is unclear and highly context-dependent (Meli, Benayas, Balvanera, & Ramos, 2014; Moreno-Mateos, Power, Comín, & Yockteng, 2012).

Freshwater habitat restoration may thus simultaneously contribute to both climate and biodiversity objectives (Muhar et al., 2016), even if ecosystem structure or function does not recover to reference condition. Future policies should emphasize the political expediency of habitat restoration and intensified management in existing protected areas. Explicit, quantitative goals for river and wetland restoration (e.g., Dinerstein et al., 2019) would enable governments to take advantage of existing conservation infrastructure to address both climate and biodiversity goals. This does not replace the need to protect additional natural areas, and this strategy should not be viewed as an alternative to land acquisition for biodiversity conservation. Because wetland restoration often does not reach reference condition, restoration should be given lower priority than the preservation of ecologically intact systems.

4.2.4 | SR7: The identification and adoption of flagship umbrella species is a valuable step for increasing recognition and prioritization of the freshwater biodiversity crisis

The urgency of freshwater biodiversity conservation is greatly undermined by an apparent invisibility to much of society, engendering an "out of sight, out of mind" mentality that limits public engagement and concern. To increase engagement with freshwater biodiversity loss and protection, charismatic megafauna could act as ambassadors of freshwater biodiversity (Kalinkat et al., 2017; van Rees, 2018). Such species have often undergone dramatic declines, and fewer than six megafauna species remain in much of Europe (He et al., 2019). Actions to promote public and political engagement with these flagship freshwater species would give freshwater ecosystems a "face" and may motivate the public to conservation action (Kalinkat et al., 2017; van Rees, 2018). Flagship species are well recognized by many European freshwater management and conservation organizations and the broader public and are often a focus of initiatives in the EU LIFE program. For example, sturgeons (Acipenseridae) are promoted as flagships for the Danube River. Use of the Red-crowned crane (*Grus japonensis*) as a flagship umbrella species in Japan helped raise awareness and funding for wetland conservation (Senzaki, Yamaura, Shoji, Kubo, & Nakamura, 2017). Biodiversity strategies focused on freshwaters should take advantage of the political power (*sensu* van Rees et al., 2019) and conservation efficacy of flagship species.

4.2.5 | SR8: Improve the global evidence base for IAS impacts and the selection of IAS indicators of freshwater habitat status

IAS disproportionately impact freshwater biodiversity (Dudgeon et al., 2006; Reid et al., 2019). All stakeholders need awareness of IAS risks, and species invasions must be managed via identification and prioritization of the most harmful species. Lists of priority invasive species (McGeoch et al., 2016) highlight the direct and indirect implications for regulatory frameworks. The EU IAS Regulation directly imposes prohibitions on trade, and places obligations regarding the pathway action plans, monitoring, and management on Member States. Indirectly, lists of impactful species are also used to assess ecological status of freshwater habitats in the EU (Boon et al., 2020). There are now conservation status assessments for the HD, which could guide standardized assessments of IAS impacts on freshwater biodiversity beyond Europe. The Environmental Impact Classification of Alien Taxa scheme (EICAT; Blackburn et al., 2014), which was adopted as the IUCN standard in 2020, provides a unified classification to assess trends in IAS impacts and management (Hawkins et al., 2015). EICAT assessments are ongoing in the Iberian Peninsula within the framework of the Invasaqua Life+ project. We recommend using clear criteria and transparent processes to select such species and ensure a coherent approach (Vanderhoeven et al., 2017).

Repeated impact assessments provide a useful indicator of IAS pressures on freshwater ecosystems (Aichi Target 9; GEO BON, 2015). Beyond increasing the number of species targeted for prevention and management (Tickner et al., 2020, Action 5), harmonizing IAS listings across CBD parties or EU member states will improve consistency across policy regimes (e.g., Natura 2000, WFD), balance conservation trade-offs between native and invasive species, and facilitate biosecurity. However, the European IAS listing is solely based on risk assessments, leaving risk management to the Member States without regional or European coordination (Booy et al., 2017). At the global scale, we recommend that risk management objectives for freshwater IAS are harmonized across CBD and EU parties. Complete eradication of freshwater IAS is often difficult, yet reduction leads to recoveries in ecosystem structure and function (Havel, Kovalenko, Thomaz, Amalfitano, & Kats, 2015). Future strategies require more holistic management, mitigating IAS impacts while reducing other forms of environmental degradation that exacerbate invasion impacts (Francis, 2012).

4.3 | Planning and accountability modalities

4.3.1 | SR9: Freshwater monitoring programmes should be reviewed, better coordinated, and funded at national and global scales

Monitoring is essential for adaptive (co)management, yet is often given insufficient attention. Europe's WFD specifies a monitoring program, and although improvements are needed for it to fully inform management and policy needs (Waylen et al., 2019), its distinction between surveillance, operational, and investigative monitoring enables consistent assessments of status, investigation of problems, and appraisal of interventions.

Long-term monitoring of important freshwater biodiversity variables (e.g., species diversity, population size, habitat quality) that capture ecological responses over long time scales (overcoming shifting baselines; Hillebrand et al., 2018) requires improvement in Europe and beyond. Europe's assessments of inland water bodies use multiple ecological indices (Birk et al., 2012) but capture only a subset of the total biota and have no central data repository, impeding large-scale research (Hering et al., 2010). Such resources would greatly improve the capacity for science-based management of freshwater biodiversity, especially for e-flows and heavily exploited species (Figure 2; Actions 1 & 4; Tickner et al., 2020). Additionally, monitoring in freshwaters has been geographically and taxonomically biased (Alahuhta et al., 2018; Arle, Mohaupt, & Kirst, 2016; Jackson et al., 2016) and requires efforts to address existing blind spots.

Globally standardized monitoring strategies would facilitate more efficient and effective monitoring, especially regarding population trends and distributions for the IUCN Red List. Upscaling of conservation monitoring is an important priority for quantifying environmental change and is essential for species listings. Initiatives like the GEO BON's Essential Biodiversity Variables and the Freshwater BON could guide standardization (Turak et al., 2017).

We also recommend financial and institutional support for monitoring freshwater biodiversity variables, as well as trans-national coordination and database integration (see SR10). Monitoring is often constrained by funding limitations, necessitating greater long-term financial support (Haase et al., 2018; McDowell, 2015). Some opportunities for cost-saving may arise from harmonization and data sharing with other policies, such as Europe's WFD with the Natura 2000 Directives. International efforts like GLEON (Weathers et al., 2013) and ILTER (Mirtl et al., 2018) offer excellent examples of how global networks can coordinate data collection and make monitoring data available for a variety of audiences. Such initiatives will not only benefit research, but enable evaluations that support evidence-informed decision-making.

4.3.2 | SR10: Hydrological and biological freshwater data should be managed according to the FAIR principles to support data mobilization and access

The availability and rapid mobilization of large datasets is essential to assessing the impacts of multiple stressors and management interventions on freshwater biodiversity (Linke et al., 2019). Although most freshwater monitoring initiatives are publicly funded, the data generated are often difficult to obtain, impeding efficient analysis of large-scale trends (Schmidt-Kloiber et al., 2019). Adherence to the FAIR data principles (*findable, accessible, interoperable*, and *reusable*; Wilkinson et al., 2016) as well as the development of institutional Open Data policies (De Wever, Schmidt-Kloiber, Gessner, & Tockner, 2012) would greatly improve access to freshwater data. Strategies advocating the collation of biodiversity data according to FAIR principles are already implemented within the Global Biodiversity Information Facility (GBIF)—a suitable repository for freshwater biodiversity data. In Europe, data portals like WISE (Water Information System for Europe) or BISE (Biodiversity Information System for Europe) could be further expanded and the Freshwater Information Platform (FIP) could guide similar endeavors (see SR 9). Monitoring data on physical (hydrological) parameters, and access to those data, are also critical to freshwater biodiversity conservation, especially for advancing flow-ecology research (Kennard, Pusey, Olden, & Marsh, 2010; Arthington, Kennen, Stein, & Webb, 2018). Given the vulnerability of publicly funded stream gage networks and the recent decline in hydrological monitoring (Ruhi, Messager, & Olden, 2018), funding for and increased prioritization of such efforts should be considered key actions for freshwater biodiversity.

4.3.3 | SR11: Future biodiversity monitoring schemes should take advantage of novel research methods and data sources

Few data are available on the distribution of most freshwater species, particularly for groups like parasites, meiofauna, protists, fungi, and bacteria, although these play a critical role in ecosystem functions (Grossart et al., 2019). The augmentation of routine monitoring schemes with novel, emerging methods could shrink these gaps and promote a more complete understanding of freshwater biodiversity (Thackeray & Hampton, 2020). Emerging methods include environmental DNA (eDNA) for species detection, metabarcoding, metagenomics, and metatranscriptomics for taxon diversity, and proteomics for functional processes. Remotely sensed earth observation data, and *in situ* high-frequency monitoring are being demonstrated and validated as useful tools for tracking ecosystem change (Carvalho et al., 2019; Mächler, Deiner, Steinmann, & Altermatt, 2014; Pochardt et al., 2020). Monitoring may also benefit from nontraditional data sources (Waylen et al., 2019), including citizen science (e.g., Biggs et al., 2015; Stat et al., 2019) and social media (Jarić et al., 2020). The emerging field of conservation culturomics (Ladle et al., 2016) uses digital text or other public data to analyze human-nature interactions. Jarić et al. (2020) describe using internet and social media data to track biodiversity patterns as *iEcology*. Notably, the greatest potential for further improvement occurs where emerging technologies are integrated. For instance, combining citizen science-based large-scale sampling with molecular detection tools proved useful in analyzing the distribution of great crested newts, an at-risk species in the United Kingdom (Biggs et al., 2015). In another recent example, Stat et al. (2019) showed that combining camera based visual surveillance with eDNA greatly enhanced fish community detection in Australia. Future strategies that support the development of these and other emerging research methods would greatly benefit freshwater biodiversity conservation.

4.3.4 | SR12: Future policies should encourage strategic planning in catchment management to balance human and wildlife water needs

The transboundary nature of freshwater ecosystems, often conflicting demands for ecosystem services, and their importance to multiple stakeholders requires strategic planning (Seliger et al., 2016). Strategic planning integrates information on species distributions, ecosystem services, management priorities, and societal needs in a transparent and repeatable process. Current approaches include multicriteria decision analysis (Langhans et al., 2019), spatial optimization algorithms (Álvarez-Miranda, Salgado-Rojas, Hermoso, Garcia-Gonzalo, & Weintraub, 2019), and integrated assessment models at various geographical scales (Boelee et al., 2017; Moe et al., 2019). Many improvements to spatial planning and decision support tools have been developed and implemented in Europe that consider the complexities of freshwater, and issues such as social equity and fairness (Domisch et al., 2019). New strategies should take advantage of available decision-support tools to navigate the complexity of freshwater ecosystems and societal demands. These can inform and enhance decision-making at the catchment scale, help handle trade-offs, and foster support through community-inclusion. Strategic planning methods will benefit from inter- and transdisciplinary research and clear objectives where the multiplicity of interests are accounted for (van Rees et al., 2019; SR14).

4.4 | Cross-cutting issues and approaches

4.4.1 | SR13: National- and local-scale biodiversity strategies pertaining to freshwater species listing and protection should be better informed by global assessments

The IUCN Red List is the most comprehensive global source of information on species extinction risk and a central reference for setting conservation priorities (Rodrigues, Pilgrim, Lamoreux, Hoffmann, & Brooks, 2006). It already contains information about > 30,000 freshwater species and should be used more directly to inform regional priorities. In the EU, a large proportion of threatened biodiversity is not adequately covered by Natura 2000; this is especially true for freshwater species. Only 14% of European freshwater fish, 3% of nonmarine molluscs, and 19% of dragonflies listed as threatened in the IUCN Red List are designated under the HD (Hermoso et al., 2019; Kalkman et al., 2010). These gaps limit the EU's capacity to respond effectively to current and future conservation challenges. Where bureaucratic and political obstacles make revisions of national priorities difficult, Red-Listed species could be prioritized for funding under other programmes (e.g., LIFE in the EU; Hermoso, Clavero, Villero, & Brotons, 2017). Red List species that are not nationally protected could be highlighted using alternative mechanisms at the national scale, like Prioritized Action Frameworks and site management planning in the EU Natura 2000 system. At the global scale, CBD parties should be encouraged to consider IUCN data and listings in national prioritizations. The quality of IUCN assessments is highly dependent on data collected at national or regional scales, so further efforts are needed to improve and sustain basic data collection from such sources, especially for the many freshwater taxa that are data-deficient. The interdependence of national reporting and global IUCN listing is worth acknowledging, as IUCN listings ultimately rely on local information from across a species' distribution. Nonetheless, the broader conservation context of a given taxon can be a useful tool in prioritization where local information is lacking.

4.4.2 | SR14: Future policies should support research and management that enhance the interactions between IWRM and ecological integrity for freshwater biodiversity conservation

Integrated Water Resources Management (IWRM) has become the global standard for sustainably managing freshwater and addressing transboundary water conflicts (Allouche, 2016), and governs management in the WFD. However, its stakeholder-based, ideally Habermasian (i.e., based on convening stakeholders) approach is not readily compatible with the highly technical nature of freshwater ecological data used for freshwater biodiversity decision-making (Smith & Clausen, 2018; van Rees et al., 2019). The prevalence of multiple stressors on freshwater ecosystems, the mobility of water throughout the phases of the hydrological cycle, and the mismatch of temporal scales between water resource use and ecological response further increase the technical difficulty of this challenge (van Rees et al., 2019). Flow–response relationships (Tonkin et al., 2019) are essential for understanding the ecological impacts of societal water use, but interdisciplinary research must bridge the gap between the "top-down," expert-driven nature of ecological research and the "bottom-up" process of IWRM.

E-flows (Figure 2) conceptualize the balance between water for biodiversity and for society and receive much-deserved attention in Tickner et al. (2020)'s priority actions. A rapidly growing literature on e-flows shows great progress over the last decade (Arthington et al., 2018; Horne, Webb, Stewardson, Richter, & Acreman, 2017a, 2017b), although logistics and implementation remain a significant challenge (Horne et al., 2017b, 2017c). Frameworks for managing human–wildlife conflicts over water and streamlining the implementation of e-flows into the on-the-ground action of IWRM thus represent an important research gap (van Rees & Reed, 2015). Future policies should make use of emerging frameworks (e.g., van Rees et al., 2019) to ensure that IWRM can be implemented compatibly and effectively with e-flows to manage the unavoidable interdigitation of freshwater biodiversity and societal water needs.

4.5 | Concluding remarks

The protection of freshwater life is critical given the ecosystem services, diversity, intrinsic value, multifarious stressors, and levels of threat associated with freshwater ecosystems. Strong policy responses at the global, continental, and national scale are needed to guide the monitoring, planning, management, and conflict resolution necessary to slow and reverse losses of freshwater biodiversity. Now is the time for decisive action. Our 14 recommendations (Figure 1) for the post-2020 Global Biodiversity Framework and European Biodiversity Strategy outline changes needed to protect freshwater life in the long term. This list is by no means exhaustive but distils important points that are relevant at the European and global scales. Some of these (e.g., SRs 9, 10, & 13) are also applicable to terrestrial and marine biodiversity and can be applied to other continents. Additional recommendations from other regions, especially low- and middle-income countries and the Global South, are also greatly needed to tackle this crisis.

ACKNOWLEDGMENTS

We thank the organizers of the ALTER-Net/EKLIPSE Post-2020 Biodiversity Workshop for discussions that led to this collaboration. CBvR was supported by a Fulbright Early Career Scholar Award from the Fulbright Spain Commission, SJT by the NERC Highlight Topic "Hydroscape" (NE/N006437/1), SCJ and GK by the "GLANCE" project (01LN1320A) from the German Federal Ministry of Education and Research (BMBF), HPG by the BMBF "BIBS" project (01LC1501G1), KAW by the Rural & Environment Science & Analytical Services Division of the Scottish Government (2016–2021 Strategic Research programme), SD by the Leibniz Competition (J45/2018), AIL by FCT (CESAM; UID/AMB/50017/2019), IJ by the J. E. Purkyně Fellowship of the Czech Academy of Science, and VH by a Ramon y Cajal Contract (RYC-2013-13979). This manuscript contributes to the Alliance for Freshwater Life's vision to understand, value, and safeguard freshwater biodiversity. We thank Steve Ormerod and 5 anonymous reviewers for their helpful suggestions on improving this manuscript.

AUTHOR CONTRIBUTIONS

CBvR generated the manuscript outline and flow, coordinated meetings and discussions during manuscript idea development, and led the writing and drafting of the manuscript. KAW, AS-K, SJT, GK, KM, SD, AIL, VH, H-PG, RS, KD, TA, LD, IJ, JHJ, MTM, ADW, IG, and MCA contributed concepts and content to manuscript ideation and assisted in drafting parts of the manuscript document. AS-K drafted figures for the manuscript. SCJ assembled the initial collaborative team and first proposed the idea for this manuscript, contributed content and writing to the manuscript, and assisted CBvR with logistical tasks in manuscript leadership.

ETHICS STATEMENT

No work on human nor animal subjects was conducted for this study.

DATA ACCESSIBILITY STATEMENT

This manuscript involved no data collection or analysis and therefore has no data to make available.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: van Rees CB, Waylen KA, Schmidt-Kloiber A, et al. Safeguarding freshwater life beyond 2020: Recommendations for the new global biodiversity framework from the European experience. *Conservation Letters*. 2020;e12771. https://doi.org/10.1111/conl.12771