Bridging the data gap in freshwater biodiversity conservation monitoring: global indicators and online data systems

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Abstract

Freshwater ecosystems are among the most threatened on Earth. Global efforts to conserve biodiversity through multilateral environmental agreements (MEAs) explicitly include goals contributing to freshwater ecosystems, but monitoring their impact is often constrained by issues around data availability and access, affecting countries' ability to plan conservation responses and apply adaptive management. Although online data systems and associated metrics and indicators are proliferating, there has been no assessment of data availability against user needs in the context of global conservation commitments for freshwater biodiversity. Therefore, this study set out to determine what indicators are being used to monitor delivery of MEA goals and targets relating to freshwater biodiversity, and to what extent these needs are met by existing online data systems.

The conventions on Biological Diversity, Migratory Species and Wetlands have between them adopted, recommended or listed 149 indicators that are relevant to freshwater biodiversity . We identified 68 metrics and 95 online data systems of potential use in monitoring these indicators. Existing data allow us to determine trends in some elements of freshwater biodiversity. However,

several challenges exist. Data on pressures to freshwater biodiversity are patchy, and data for the state of biodiversity at the species level tend to be biased towards vertebrates and terrestrial species compared with aquatic taxa. Response indicator data focus on protected and conserved areas, but are weak on measures of the extent and quality of ecosystem restoration. Data on species management focus almost exclusively on the coverage of different assessments or databases, rather than actions and policies to conserve and restore species. The broad suite of benefits provided by freshwater ecosystem services are not well captured in either the MEA indicator frameworks or the available data sets. One of the biggest challenges in using existing data included aligning distribution data with specific biomes or ecosystem functional groups. We discuss the implications and the action needed to improve data coverage for freshwater indicators for MEAs. However, given the perilous decline in wetland habitats and species, we cannot wait for all the data issues to be resolved before we tackle the pressures on freshwater biodiversity.

Introduction

Freshwater ecosystems, including lakes, rivers, streams and artificial wetlands, host critical components of global biodiversity (Convention on Wetlands, 2025a). While covering less than 1% of the Earth's surface, they provide habitats for more than 10% of known animal species, including about one-third of vertebrates (Balian et al., 2008; WWF, 2018). Wetlands and freshwater biodiversity provide a suite of vital ecosystem services (Lvnch et al., 2023), including hydrological buffering, water purification and coastal protection (Mitsch & Gosselink, 2000; Gardner et al., 2015), as well as climate regulation (Creed et al., 2026). Hundreds of millions of people depend on freshwater fisheries as a source of low-cost protein (McIntyre et al., 2016), with regions such as Southeast Asia obtaining up to 80% of their dietary protein intake from freshwater species of the lower Mekong (Orr et al., 2012).

However, freshwater ecosystems are under threat. An estimated 35% of wetlands have been lost since 1970 (Dudgeon et al., 2006; Davidson, 2014; Darrah et al., 2019; Convention on Wetlands, 2025a), driven by habitat modification, fragmentation and destruction (primarily from conversion to croplands, settlements and damming) water abstraction (especially for agriculture), overfishing, pollution, and climate change (Strayer & Dudgeon, 2010; IPBES, 2019; WWF, 2024; Fluet-Chouinard et al., 2023; Convention on Wetlands, 2025a). Dams and reservoirs and the associated fragmentation and regulation of environmental flows lead to the loss of river connectivity (Lehner et al., 2024), and only 37% of rivers longer than 1,000 km are now free-flowing over their entire length (Grill et al., 2019). Furthermore, small hydropower plants (SHPs) represent an often overlooked, but major threat to smaller streams through fragmentation, changes in temperature and oxygen contents. Yet despite the presence of over 83,000 known SHPs, they are generally promoted as a form of sustainable power, and their influence on biodiversity routinely overlooked (Couto & Olden, 2018; Lange et al., 2018).

A quarter of freshwater animal species assessed for the IUCN Red List of Threatened Species are considered threatened with extinction (Sayer et al., 2025). Some taxa, however, are under greater threat: close to one third of freshwater mollusks and more than 40% of amphibians are threatened (IPBES, 2019; Böhm et al., 2021); data from Species+ and the IUCN Red List of Threatened Species show that 22 of the 24 freshwater fish species listed under the Convention on the Conservation of Migratory Species of Wild Animals (CMS) are globally threatened; and 30% of freshwater decapod crustaceans are threatened, with 39% Data Deficient (Sayer et al., 2025). In the last 50 years, the average abundance of freshwater vertebrate species populations declined by 85% (WWF, 2024), disproportionately high when compared with other biomes. The loss and fragmentation of wetlands and freshwater biodiversity leads to a suite of environmental impacts, including those affecting the quality and supply of terrestrial water, carbon balance, greenhouse gas emissions, flood regimes and groundwater recharge (Fluet-Chouinard et al., 2023).

Efforts have been made to protect important sites but protected area planning does not adequately account for the needs of freshwater ecosystems (Leal et al., 2020). Global efforts to reverse the loss of nature, including freshwater biodiversity, focus on several multilateral environmental agreements (MEAs), primarily the Kunming-Montreal Global Biodiversity Framework (KM-GBF) of the Convention on Biological Diversity (CBD), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and the CMS. The Convention on Wetlands (CoW) specifically targets freshwater habitats, while the CBD set explicit targets for the restoration and protection of inland waters for the first time in 2022 under the KM-GBF. The Sustainable Development Goals (SDGs), adopted by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development, in some cases provide added motivation for countries to act and report on environmental issues. For example, SDG indicator 6.6.1 on the extent of wetland habitats is closely tied to the Convention on Wetlands.

Many conservation organizations, whether government agencies or NGOs and foundations, have committed to conserving freshwater biodiversity. Increasingly, businesses from the public and private sector are also committing to Nature-positive environmental goals and related reporting and disclosure, as demonstrated by adoption of guidance and standards such as the Science-based Targets Network (SBTN, 2024a,b) and the Taskforce on Nature-Related Financial Disclosures framework (Ceres, 2022; TNFD, 2023a,b). Therefore, all actors in freshwater biodiversity conservation, from governments to civil society to business and financial institutions, need data on the state of species and habitats and on the pressures they face in order to monitor and report on progress, apply adaptive management and make informed decisions (Bakker & Teske, 2025; Haase et al., 2025). Data on biodiversity are being shared through a proliferating array of online databases and data platforms (McOwen et al., 2025; Stephenson, 2025; Kemp et al., in press), and several freshwater-specific data sources exist (e.g.,, Shen et al., 2024; Convention on Wetlands 2025b; Reygondeau et al., 2026). Ongoing work by the Nature Positive Initiative (2026) to confirm a set of state of nature metrics will also likely influence future business monitoring efforts.

Nonetheless, freshwater biodiversity data – like many types of biodiversity data – are often difficult to access, challenging to align with other sources of data, with blockages ranging from the usability and quality of data, willingness to use data, capacity to collect data to the lack of data sharing and smaller datasets not being integrated into public repositories,(Schmidt-Kloiber & De Wever, 2018; Stephenson & Stengel, 2020; Stephenson et al., 2020), and the absence of use of FAIR data standards (Wilkinson et al., 2016). Despite substantial increases in the volume of freshwater data collected worldwide, many regions and ecosystems still lack sufficient data collection and/or data access (Smits et al., 2025). Broader challenges with biodiversity data biases and access (Hughes et al., 2021; Stephenson et al., 2022; Burgess et al. 2024; Demirel et al., 2026) also apply to freshwater ecosystems.

Although there have been some reviews of freshwater data (e.g., Schmidt-Kloiber & De Wever, 2018; Jarvis et al., 2023; Smits et al., 2025) there has been no assessment of data availability against user needs in the context of global conservation commitments. Therefore, this study set out to answer the question: what indicators are being used to monitor delivery of MEA goals and targets relating to freshwater biodiversity, and to what extent are the data needs met by online data systems.

Methods

Scope

We considered freshwater biodiversity to include species of animals, plants and fungi and habitats occurring within freshwater realms of the IUCN Global Ecosystem Typology (Keith et al., 2022; IUCN, 2026b). According to this typology, freshwater ecosystems include 22 habitats (or functional groups) in three biomes: rivers and streams, lakes, and artificial wetlands. There are also transitional biomes that cover multiple realms and these have an additional 17 freshwater ecosystem functional groups, including palustrine wetlands (e.g., marshes, peat bogs) and waters transitional between fresh and salt water, such as coastal inlets, estuaries and lagoons. The inclusion of such coastal wetlands also meant the inclusion of coastal species, such as mangroves.

Data needs: MEA indicators

The Convention on Wetlands is focused on freshwater ecosystems, including coastal wetlands to depths of 6 metres, but goals and targets under other MEAs, namely the CBD KM-GBF and CMS, explicitly or implicitly include freshwater biodiversity. We used the latest monitoring plans and indicator frameworks available for each MEA as a proxy for global freshwater biodiversity data needs (CBD, 2022, 2024; UNEP-WCMC, 2025a; CMS, 2026; Convention on Wetlands, 2026a,b). Each indicator was scored for its relevance to freshwater on a 0-4 scoring system (Table 1). Indicators scoring 3-4 are presented in Table 3; indicators scoring 0-2 are presented in Supplementary Materials (Table S1). We also reviewed indicators derived from the CITES Secretariat's non-detriment findings guidance for aquatic species for CITES (CITES Secretariat, 2024) and freshwater-related indicators for the SDGs (United Nations Statistics Division, 2026).

Table 1. Scoring system to assess relevance of MEA indicators to freshwater biodiversity.

Score	Description	Value for monitoring	Examples
4	Targets freshwater	Can be used to monitor freshwater biodiversity.	River Fragmentation Index; Wetland extent
3	Can target freshwater or be aggregated/disaggregated by F/W		Ecosystem extent; Living Planet Index (freshwater disaggregation)
2	Generic but could include or be aggregated/disaggregated by freshwater	May be able to contribute to measuring freshwater biodiversity in some situations	Zoonotic disease in wildlife; Number of countries using participatory, integrated and biodiversity-inclusive spatial planning
1	Generic but unlikely to include freshwater-specific details	Not useful for monitoring freshwater biodiversity conservation even if they are relevant for other biomes or generic conservation action.	Amount of biodiversity-related philanthropic funding; Food waste index
0	Not relevant for freshwater		Coral reef extent; Forestry Production & Trade (Wood Fuel)

We assigned each indicator to pressure-state-response-benefit (PSRB) categories, sensu Sparks et al., (2011) to conform with many MEA data analyses (e.g., Tittensor et al., 2014). We then compared the indicators in each category with frameworks for biodiversity states (Essential Biodiversity Variable Classes; Pereira et al., 2013), pressures (the CMP/IUCN Direct Threats Classification Version 4.0; IUCN & CMP, 2024; Salafsky et al., 2025) and conservation actions (IUCN/CMP Conservation Actions Classification Scheme, Version 2.0; IUCN, 2026c).

In addition, we developed a list of metrics, covering PSRB, that are being measured by different data users and providers. This list was created using inputs from Burgess et al. (2024), augmented by other lists of freshwater metrics and indicators held at UNEP-WCMC. This initial list was further improved by traditional and AI literature searches, where the existing list of resources was entered into Google and Microsoft Co-Pilot systems and these were asked to suggest resources relating to freshwater metrics and indicators that were missing. The resulting feedback was checked manually before being entered into the file. The authors of this paper also further checked and added missing metrics to this list, and helped refine the database further for use here. We assessed each metric against its relevance to freshwater biodiversity using a 0-4 scoring system (Table 2). Metrics scoring 3-4 are presented in Table 4; system scoring 0-2 are presented in Supplementary Materials (Table S2).

Data access: sources and systems

There are a range of different types of biodiversity data sources online (Stephenson & Stengel, 2020; Kemp et al., in press). Here we refer to online data systems which include web-based platforms, data bases and other tools that provide access to data on biodiversity and that could be used, or are already being used, to monitor biodiversity. Our focus is on online systems with global data, rather than regional, national or sub-national, although some regional data systems were identified (see Tables S2 and S3).

We identified existing, currently accessible online freshwater biodiversity data systems by interrogating the database developed by Kemp et al. (in press; Appendix 3a – global systems). Kemp et al. included tools and platforms produced by the authors (e.g.,, Stephenson & Stengel, 2020; Weatherdon et al., 2021; UNEP-WCMC, 2025b), complemented by extensive internet searches using traditional search engines and AI tools, and finalized by manual checks. We also used the expertise of the authors to augment that list with additional systems and to update and improve the existing database for freshwater. We assessed each data system against its relevance to freshwater biodiversity using the same 0-4 scoring system we used for metrics (Table 2). Systems scoring 3-4 are presented in Table 5; system scoring 0-2 are presented in Supplementary Materials (Table S3). We then compared the MEA indicators to the online data systems and metrics to assess how well existing systems meet the data needs.

Table 2. Scoring system to assess relevance of data systems to freshwater biodiversity. Note that, while a freshwater-specific tool scoring 4 may be more focused on the biome, a freshwater subset of an all-taxa/ecosystems tool may be more useful for monitoring if the data contained are more relevant for the set of indicators.

Score	Description	Value for monitoring	Examples
4	Data system or metric focuses on freshwater biodiversity	Expected to provide data of use in monitoring MEA indicators.	Aquastat, Global Mangrove Watch
3	Includes freshwater biodiversity data or data that can be aggregated or disaggregated by F/W (or should be able to in future when sufficient data are available)		IUCN Red List of Threatened Species, UN Biodiversity Lab, World Database of Key Biodiversity Areas
2	Includes or may include some data on freshwater species or habitats which might be possible to access now or in the future	May be able to contribute to measuring some indicators.	Kew Data portal, OBIS
1	Unlikely to include freshwater-specific data of use	Not useful for MEA monitoring for freshwater biodiversity.	Mycobank Database, Seabird Tracking Database
0	Not relevant for freshwater biodiversity		Climate Funds Explorer, Forest Link

Results

Indicators and related data issues across MEAs

The three MEA monitoring frameworks assessed here included a total of 149 indicators evaluated as relevant to freshwater biodiversity (Table 3; Figure 1). Across CMS, CoW and the CBD KM-GBF, response indicators formed the largest group, accounting for 70 indicators, or 47% of the total. These were followed by state indicators (43 indicators, 29%), pressure indicators (24 indicators, 16%) and benefit indicators (12 indicators, 8%). The KM-GBF accounted for the largest number of freshwater-relevant indicators (80; 54%), followed by CoW (50; 34%) and CMS (19; 13%).

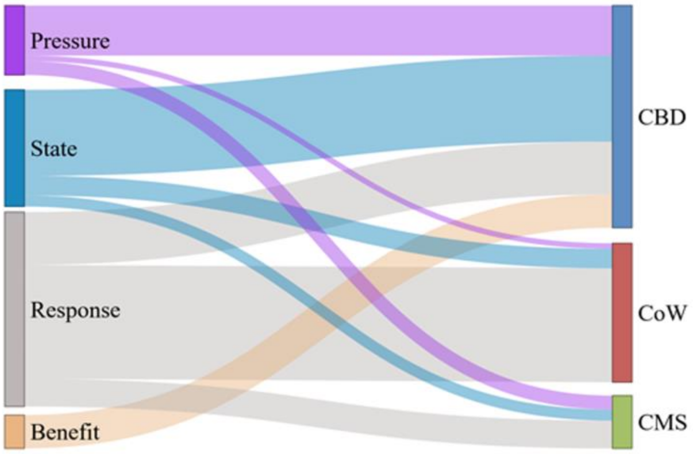

Figure 1. Sankey diagram showing the distribution of freshwater-relevant PSRB indicators across the CBD KM-GBF, CoW and CMS. Flow widths are proportional to the number of indicators. Numbers refer to indicators evaluated as relevant to freshwater biodiversity and listed in Table 3 (n = 149).

Pressures

Pressure indicators were unevenly distributed across the three MEAs (Table 3; Table S4). The KM-GBF and CMS each included approximately one quarter of their freshwater-relevant indicators as pressure indicators, 23% and 26%, respectively, whereas CoW included two pressure indicators, representing 4% of its freshwater-relevant indicator set. Pressure indicators used mainly addressed land-use change and other forms of natural system modification, pollution and direct resource use such as fisheries. More specifically, eight pressure indicators related to land-use change or natural system modification, seven to pollution, six to direct resource use, three to invasive alien species and one to climate-change impacts on migratory species. Invasive alien species and climate change were therefore less extensively covered, while human intrusions and disturbance were not represented among the identified freshwater-relevant pressure indicators.

States

State indicators included 42 indicators across the three MEAs (Table 3; Table S5). These indicators mainly focused on the condition, status and trends of species, habitats and ecosystems. The largest group related to conservation status or extinction risk, particularly for species and, to a lesser extent, habitats. Several state indicators were derived directly from the IUCN Red List of Threatened Species, including multiple disaggregations of the Red List Index. Other state indicators described habitat extent, ecosystem structure, water quality, environmental flows and ecological integrity or intactness. Indicators linked to species populations, including abundance and population trends, were also present. Fewer indicators addressed ecosystem functioning, community composition, genetic composition or species traits.

Responses

Response indicators were the dominant class, with 70 indicators across the three MEAs (Table 3; Table S6). Most were focused on site designation, area-based protection, management effectiveness, wetland inventories, reporting, policy integration, capacity-building and institutional implementation. Fifteen freshwater-relevant response indicators focused on site and area protection, mainly through the designation of protected and conserved areas, Wetlands of International Importance (Ramsar sites) or Key Biodiversity Areas (KBAs). A further set addressed site management and stewardship, including management effectiveness of protected and conserved areas and wetland sites. Species-focused response indicators were mainly linked to conservation assessments, CMS instruments or related reporting mechanisms. Fewer response indicators directly addressed ecological restoration, invasive species management, livelihood and economic incentives or long-term conservation finance.

Benefits

Benefit indicators were the smallest PSRB class, with 12 indicators, all identified under the CBD KM-GBF (Table 3). These indicators mainly related to benefits derived from the use of wild species, utilized species or species contributing to ecosystem services (sometimes referred to as nature's contributions to people or NCPs). Around half were based on indices of abundance or conservation status, including Living Planet Index or Red List Index measures for used, traded, migratory or service-providing species. Three indicators were linked to sustainable fisheries, including the proportion of fish stocks within biologically sustainable levels, spawning stock biomass and a sustainable watershed and inland fisheries index.

Trends across indicators

The distribution of indicators differed among MEAs. CoW contributed 41 of the 70 response indicators, corresponding to 59% of all response indicators and 82% of its own freshwater-relevant indicator set. The CBD KM-GBF contributed most state indicators, with 31 of 42 indicators, or 74%, and most pressure indicators, with 18 of 25 indicators, or 72%. All benefit indicators were identified under the CBD KM-GBF. CMS contributed 10 response indicators, five pressure indicators and four state indicators, corresponding to 53%, 26% and 21% of its freshwater-relevant indicator set, respectively.

Although the three MEAs monitor similar aspects of biodiversity, only a handful of indicators relevant to freshwater are common across MEAs (Table S7).The CBD KM-GBF and the CMS both use the Red List Index disaggregated by alien invasive species and species subject to pollution and utilization; both of these MEAs also monitor free-flowing rivers. The Convention on Wetlands has the same or very similar indicators as the CBD for species (fish) abundance, Red List of Ecosystems for wetland habitats, protected areas coverage, protected areas coverage of wetland KBAs, and area under restoration.

Indicators addressing species and habitat restoration outcomes, invasive alien species management, climate-change pressures, economic incentives, livelihoods and financing mechanisms were less frequent. Many CBD KM-GBF indicators already have identified datasets or potential data sources to support monitoring, although several indicators remain under development and some proposed indicators still lack clearly identified data sources. A further issue is that many indicators that could be relevant to freshwater biodiversity are not currently disaggregated by biome for freshwater systems. This applies, for example, to several Red List Index-based indicators, including those for migratory species, traded species, utilized species, species used for food and medicine, and Red List Indices showing trends driven by different pressures, such as pollution, invasive alien species impacts etc. This is because disaggregating the Red List Index across multiple dimensions simultaneously leads to too few species driving trends, weakening the reliability of the resulting trends.

Other international monitoring frameworks

Several 'daughter agreements' under the CMS also have monitoring systems at a regional level. For example, the **Agreement on the Conservation of African-Eurasian Migratory Waterbirds** (AEWA), a regional flyway-focused MEA which aims to coordinate the conservation and management of 254 avian species that are ecologically dependent on wetlands for at least part of their annual cycle, has adopted a set of indicators to monitor progress towards the Agreement's Strategic Plan 2019-2027 (AEWA, 2018; Hearn et al., 2018).

Progress towards implementation of the Agreement is informed by data sources such as national reports submitted by AEWA Contracting Parties, population status and trend data gathered by the African-Eurasian Waterbird Census (a regional program of the International Waterbirds Census) and information on key flyway sites compiled in the Critical Site Network tool, as well as more specific assessments relevant to issues such as adaptive harvest management. The AEWA Conservation Status Report series (e.g.,, Nagy et al., 2025) analyses the data needed to evaluate progress with the AEWA Strategic Plan indicators; the series currently alternates on a six-year cycle between a comprehensive report on waterbird population status and trends, and a report focusing on drivers and responses. The AEWA includes various initiatives such as the African-Eurasian Waterbird Census (a regional program of the International Waterbirds Census (IWC), coordinated by Wetlands International), the African-Eurasian Waterbird Monitoring Partnership, and the AEWA Conservation Status Reports, aimed at monitoring the status of waterbirds, adapt management strategies, and influence decision-making concerning waterbird populations.

Determining which species are covered by CMS and AEWA also relies on data. For example in CMS distribution data are needed to understand which species Parties are Range States for, which ultimately sets their obligations; in AEWA, conservation status and trend information directly sets the level of protection that different AEWA populations receive.

In order to identify species to list in its appendices and to regulate or ban international trade, **the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** requires metrics on population status and the level of offtake, as well as various life history parameters. Based on non-detriment findings (NDF) guidance for aquatic species produced by the CITES Secretariat (2024), it is implicit that data will be required on the state of habitats, level of offtake, fisheries effort, composition of catches (species, size, sex and maturity), fisheries range and level of trade. Risk assessment approaches to help calculate NDFs also need life history data such as maximum age, maximum size, growth rate, natural mortality, recruitment, age at maturity, schooling behavior and seasonal migrations.

Although not an MEA, the **Sustainable Development Goals** (SDGs) have several biodiversity focused goals and targets, and indicators around goals 6, 14 and 15 are especially pertinent for freshwater. Many overlap with the indicators used for the CBD KM-GBF. Contracting Parties to the CoW that conduct National Wetland Inventories are also able to report on certain SDG indicators, especially 6.6.1 (Change in the extent of water-related ecosystems over time) and 15.1.2 (Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type).

Existing data

Metrics and associated data

Our review beyond the three MEAs located 68 metrics and indicators with freshwater relevance scores of 3 or 4 (Table 4; Fig. 2). Some are available within online data sources and systems, whereas others are presented as specific measures in scientific papers or reports. These represent biodiversity pressures, states, responses and benefits that have been measured or will be measured. We analyzed these in terms of their relevance to the PSRB indicator framework and to different facets of biodiversity (genes, species, ecosystems) and NCPs. A single metric may be relevant to more than one category, so the counts are not mutually exclusive.

Pressure and state were the most frequently represented while pressure was corresponding to 79%, and state was 72% of the reviewed set. Response and benefit were less frequent, with 21% and 20%. Further, ecosystem-related indicators were the most common (56%) followed by species-related (21%), and NCP-related (19%). Only one metric or indicator was related to genes.

When the metrics and indicators already in use were compared with MEAs and other policy linkages, the strongest connections were with CBD and CoW, mainly through measures relating to pressure and state. SDG linkages were also evident, including a relatively higher representation of response and benefit measures.

Global online data systems

We identified 95 global data systems of relevance to freshwater biodiversity (Table 5; Figure 2). Each of these systems includes data that can be used to help monitor freshwater species and habitats, or could be used if aggregated or disaggregated in a suitable way, at least for some countries.

The majority of systems (35%) can monitor multiple types of indicator; these systems include large platforms curated by international organizations and their partners that house multiple datasets, such as FAO's Data Explorer, FishStat AquaGris and AquaSTAT, and systems involving UNEP or UNEP-WCMC such as Global Freshwater Quality Database GEMStat, MapX, Species+, UN Biodiversity Lab, and World Water Quality Hub. Most systems were generic in scope, while a smaller group was more directly oriented toward scientific users and fewer systems were oriented toward government or business users.

A quarter of systems focus on state indicators, and 21% can be used for states and pressures, 7% more explicitly on pressures (e.g., Global Dam Watch, Global Fish Invasions Database). Ten percent can be used to some extent to monitor benefits from freshwater biodiversity , but only 1% (one system) was identified to monitor a specific response: Protected Planet, the World Database on Protected and Conserved Areas. In the data systems scoring 1 and 2, only a further 16 were identified as offering any potential response data.

Of the 47 online data systems focused primarily on freshwater biomes (i.e. scoring 4 for relevance), several focus on freshwater species (e.g.,, FreshLanDiv, FreshVerts, Freshwater Biodiversity Data Portal, International Waterbird Census Database), rivers and wetlands (HydroSHEDS, Ramsar Sites Information System, Global Swimways), specific habitats likes mangroves (Global Mangrove Watch) or peatlands (Global Peatland Database), water flow and hydrology (e.g., Caravan, HydroShare, Global Runoff Data Center), water quality (e.g., GEMStat, World Water Quality Hub) and water risk (CDP's Water Watch, WRI's Aqueduct, WWF's Water Risk Filter).

Across system types, data portals and decision-support tools formed the main groups, followed by libraries or catalogues, repositories and other data systems. These systems were most often linked to ecosystem data, species data, Earth observation, natural capital or ecosystem service information, and general freshwater-relevant data. Genetic data, trade-related data, business impacts and risks, climate change or disaster risk reduction, and area-based or land-use planning were represented by fewer systems. Some data systems include very early records. For example, the oldest protected area in Protected Planet is Bogd Khan Mountain in Mongolia, established in 1778. GBIF holds records from centuries ago, such as an Indo-Malay Galliformes record from 1648 (Newcastle University, 2020).

Some systems that cover multiple biomes, such as the IUCN Red List of Threatened Species, the World Database on KBAs and the UN Biodiversity Lab, include a search function to select data by biome or keyword, making it easier to access freshwater data.

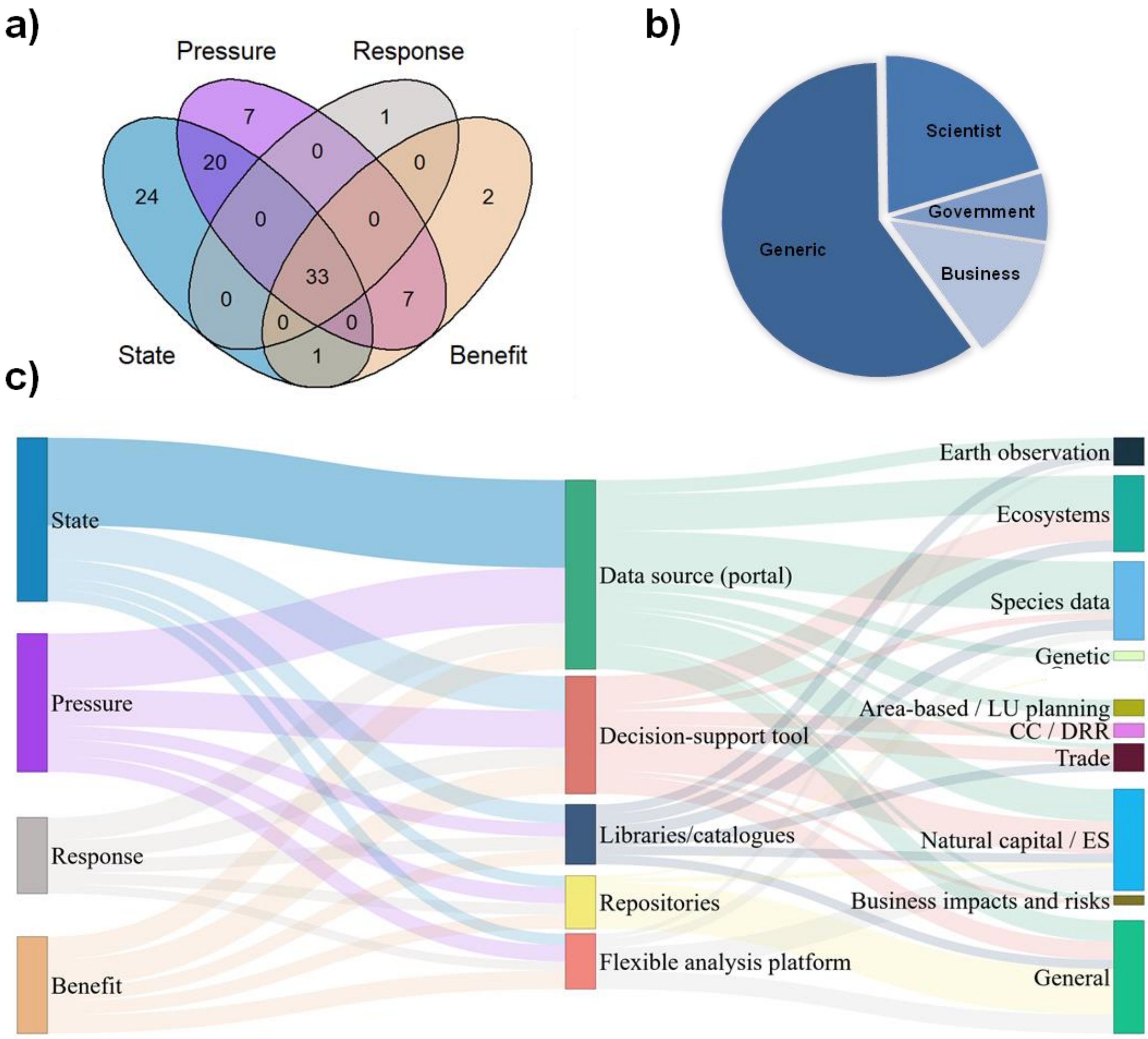

Figure 2. Structure and use of global online data systems. a) Number of and overlap within the PSRB framework; b) Distribution of primary user groups (to the extent they can be determined) for global online data systems; (c) Sankey diagrams for linkages between PSRB categories, type of online data system, and main type of data included, respectively.

A key data source for monitoring for CITES is the CITES Trade Database. However, although this is a valuable tool for understanding trade in listed species, its analysis and interpretation need to take account of various conditions and limitations, including the original sources of data (e.g., gross or net trade reports, importers or exporters) (Robinson & Sinovas, 2018). Illegal trade further complicates efforts to monitor and manage wildlife trade (Hughes et al., 2026). Data from the IUCN Red List can also be used to help identify species that potentially meet the criteria for CITES listing (Challender et al., 2023). Data from the International Waterbird Census Database are key in monitoring bird population trends in flyways covered by AEWA, allowing the production of occasional reports (e.g.,, Nagy & Langendoen, 2020).

The International Waterbird Counts coordinated by the Wadden Sea Flyway Initiative, Wetlands International and BirdLife International, and involving many in- country teams provides annual count data for waterbirds using the East Atlantic Flyway. The data are pooled together and analyzed annually, providing information on waterbird abundance, including flyway population sizes, flyway population trends, numbers and trends at key sites. The database also contains information that enables monitoring of environmental conditions (pressures and conservation measures) at the sites (van Roomen et al., 2025).

Data needs against data availability

Data needs met or partially met

While the usability of any given data system to measure any given indicator at the national or global level will obviously depend on the time series available, and the taxa and habitats covered, we can see some overall trends in the availability of freshwater biodiversity data. There are several global databases that can help monitor pressure indicators around some forms of land use change and natural system modifications (e.g.,, Global Dam Watch, Free-Flowing Rivers), some types of pollution relating to water quality (especially through UNEP's GEMStat), and some forms of biological resource use, such as levels of trade and fisheries (e.g.,, AquaSTAT, CITES Trade Database). Data on invasive species are available for some taxa (e.g., Global Fish Invasions Database). The Red List index (RLI) can also be disaggregated to track species' extinction risk driven by certain pressures (invasives, pollution etc).

To measure state indicators, several data systems provide data on the trends in species abundance, conservation status or extinction risk (e.g.,, FreshLanDiv, FreshVerts, ZSL Living Planet database, IUCN Red List of Threatened Species, International Waterbird Census Database), as well as the extent and conservation status of habitats (e.g., Global Peatland Database, Global Mangrove Watch, Global Wetlands, HydroSHEDS, IUCN Red List of Ecosystems). Indeed, due to the ability to measure habitat extent from Earth observations, the state of habitats may be the best monitored indicators, with the online systems and metrics focusing especially on mangroves and peatlands. However, the extent of coverage for different freshwater species and habitats, as well as temporal and spatial coverage of each taxon or habitat, will vary between countries. Water quality, essentially a measure of the quality of freshwater ecosystems, is also covered by several data systems (e.g., GEMStat, World Water Quality Hub), as are various flow and hydrology measures (e.g., HydroShare, Global Runoff Data Center).

In terms of response indicators, there are extensive data on protected and conserved areas, KBAs and Wetlands of International Importance, as well as management effectiveness for many protected and conserved areas. However, the degree to which they are easy to disaggregate by biome varies.

In general, at least some data are available for most benefit indicators, due to the use of the RLI and Living Planet index (LPI) to monitor certain utilized species, and databases led by FAO and others that track fisheries. It is notable that data on benefits and NCPs are generally more widely available for indicators of use for agriculture and fisheries (commercial sectors). However, overall, the broad suite of benefits or NCPs provided by freshwater ecosystems are not well captured in either the MEA indicator frameworks or the available data sets.

There are several examples where data from global online data systems provides actors the means to measure their contributions to MEA indicators. For example:

- The ***Global Lakes and Wetlands*** Database (Lehner et al., 2025), a data product of the WWF led HydroSheds system, is used by many contracting parties of the Convention on Wetlands to undertake Tier 1 National Wetland Inventories to assess the extent of wetlands. This in turn helps them report against the Convention's goal 1 indicator and SDG indicator 6.6.1 , as well as the GBF goal 1, target 1 indicator on extent of natural ecosystems.
- The ***IUCN Red List of Threatened Species*** (IUCN, 2026a) underpins several CMS indicators, including those on: the extent to which the CMS Appendices covers all globally threatened migratory species, percentage of known migratory species that have been assessed globally by the IUCN Red List within the last ten years, as well as two conservation status indicator and various pressure indicators derived from the trends in the RLI driven by specific pressures). Various derivatives of the Red List Index can also help measure several indicators from the GBF (e.g., the RLI for migratory species, utilized species, pollinating species), as well as the Convention on Wetlands indicator for its target 1.3 (Red List Index for wetland species).

- Both the ***Global Biodiversity Information Facility, GBIF***, and the ***Living Planet database*** are the source of a GBF indicator on data record growth to measure Target 21 on the availability of biodiversity knowledge.
- The ***World Database of Key Biodiversity Areas*** and the ***World Database on Protected and Conserved Areas*** provide data that can generate indicators of protected and conserved area coverage of KBAs for freshwater species and ecosystems (relevant to KM-GBF Target 3) as well as disaggregations of this metric for freshwater species (for the Convention on Wetlands) or freshwater migratory species (for CMS).

Similarly, a number of databases and data sets linked to specific metrics (Table 4) provide additional ways to track MEA indicators globally or potentially nationally. Examples include: the Freshwater Biodiversity Intactness Index measured by the Natural History Museum, London, which can contribute to the CBD KM-GBF complementary indicator for Goal A; UNEP/GEMSWater tracking of SDG 6.3.2 – Proportion of water bodies with good ambient water quality, which can monitor the same indicator in the KM-GBF.

A range of regional and national data systems also provide data of relevance to reporting on delivery of the freshwater elements of MEAs. Examples include the Ocean Plastic project in Ireland (https://oceansplasticproject.ie/), Lakes in Spare time in Denmark (https://www.sdu.dk/en/forskning/forskningsformidling/citizenscience/afviklede-cs-projekter/soer-i-fritiden), water monitoring in rivers and lakes in Norway (https://www.niva.no/en/topics/Environmental-Monitoring), the Madagascar Wetland Knowledge Base Portal (http://www.wetlandsmada-wkb.org/) and the KAZA Online tool (https://maps.ppf.org.za/arcgis/apps/webappviewer/index.html) covering the Kavango Zambezi (KAZA) Transfrontier Conservation Area and its constituent river basins. EU Member States also use national and regional freshwater biodiversity data to report on delivery of policies such as the Birds Directive, Habitats Directive and Water Framework Directive.

Data gaps and biases

The biggest discrepancy between the type of data needed (MEA indicators), the type of data being collected (metrics being measured) and the type of data being made available (online systems) is with responses. Most (47%) MEA freshwater indicators monitor responses, yet only 21% of freshwater metrics measure responses and only 1% of online systems share data on specific responses. Metrics focus mot on pressures, while online data systems share most data on states.

Pressure data are patchy, and only available for some elements of the main IUCN categories. For example, it is hard to disaggregate data on solid waste by biome (see, e.g., Litterbase) and pollution data on energy pollution such as noise and light are difficult to extract from global sources. Other than CITES-listed species, there is little consolidated global data on the offtake and use of freshwater species. Data on climate change impacts on species and habitats are not readily disaggregated for freshwater systems.

Data for species state tend to be biased towards vertebrates and terrestrial species compared with aquatic taxa across data systems. However, specific data systems have specific biases. For example, in the Global Register of Migratory Species, sufficient information for mammals, fishes and insects is only available for economically important species. Generally, the state of genetic biodiversity is not adequately monitored.

Weaknesses for response indicator data include measures of the extent and quality of ecosystem restoration. Data on species management focus almost exclusively on the coverage of different assessments or databases (e.g., RL, GBIF), rather than actions and policies to conserve and restore species. Global data on capacity building and awareness raising are non-existent, although this likely reflects the localized nature of such conservation responses. Similarly, useful data disaggregated by freshwater is lacking for legal and policy responses and on economic incentives and conservation finance.

One of the biggest challenges in using existing data included aligning distribution data with specific biomes or ecosystem functional groups. Many of the data systems focused on marine ecosystems include some coastal or estuarine freshwater habitats or species. While the ones we scored as relevant provide some scope for accessing data, others scored as less relevant might provide some data of use at national or regional level, or are adapted in future to allow disaggregation by biome.

Discussion

Indicators

We found indicators for freshwater were sparse across MEAs, especially around species and habitat restoration, invasive species, climate change, and economic incentives. The monitoring frameworks for the Convention on Wetlands and CMS have recently been updated (CMS, 2026; Convention on Wetlands, 2026a) and likely cover most of the core needs of each convention, even if national reporting remains a challenge (e.g., Davidson et al. 2019). However, the KM-GBF indicator framework continues to have gaps. For example, the goals focused on conservation (A) and sustainable use (B) are considerably better covered by the indicator framework than those on benefit sharing and resourcing (Affinito et al., 2025). Locke et al. (2026) noted that the GBF does not address hydrology. This is a major omission because freshwater regimes, unimpeded riverine connectivity, and unpolluted water are of such significance that maintaining or restoring hydrological processes, water quality, and associated floodplain and delta habitats is the most important action for a wide variety of terrestrial, freshwater, and marine organisms. Our study suggests hydrology data exist in a number of global data sources so could be monitored.

It should also be noted that, while updated indicator frameworks are in place, they are not always applied or measured. For example, only one-fifth of indicators used in the Fifth National CBD reports matched those recommended by the secretariat (Bhatt et al., 2020). However, with the use of new technologies for monitoring biodiversity expanding and many, such as environmental DNA, being applicable to freshwater biomes (Stephenson et al., 2020; Zhang et al., 2026), we can expect to see improvements in indicator measurement and more site-level and national level data feeding into global data systems in future.

Data

We found many data systems and databases could not be disaggregated by biome, which may reflect methodological challenges or data availability (Affinito et al., 2025). Nonetheless, some biodiversity indicators have been monitored consistently within freshwater ecosystems and beyond for many years, providing valuable time-series trends and informing a range of assessments and reports on freshwater ecosystems and species linked to the delivery of global goals (e.g., Feio et al., 2023; Deinet et al., 2024; Vardakas et al., 2025).

The recent CMS study of migratory freshwater fish (Hogan et al., 2025) used data from a range of global data sources including the IUCN Red List of Threatened Species, (status, threats, population trend), FishBase (distribution, biology, movement notes), and the Global Register of Migratory Species (GROMS), as well as regional databases such as the North American Freshwater Migratory Fish Database, Mekong River Commission resources, Trans-European Swimways / Wetlands International data, South Africa River Eco-classification and New Zealand Freshwater Fish Database. In many cases, a combination of data sources can help measure key parameters or indicators. For example, a recent analysis of area of habitat for freshwater species (Ridley et al., 2026) used the IUCN Red List of Threatened Species, the Global Lakes and Wetlands Database, and GBIF. National and global data have also been analyzed to produce reports assessing the extent and state of wetlands worldwide (Convention on Wetlands, 2025a), and the quality and biodiversity of global freshwater ecosystems (Janse et al., 2026).

However, challenges and data gaps remain. Taxonomic, geographic and biome-specific gaps and biases in biodiversity data are well documented (Hughes et al., 2021, 2025, Stephenson et al., 2022, Affinito et al., 2024), as well as a lack of measures of genetic diversity (Hoban et al., 2022) and this had led to long-standing problems in reporting against global targets (Walpole et al., 2009, Tittensor et al., 2014). "The conservation status and even basic biology of many freshwater species is poorly known, especially in the tropics" (Dudgeon & Strayer, 2025). Of the species data available, there tend to be biases towards taxa such as vertebrates, crustaceans and mangroves. The vast majority of described freshwater taxa (85.5%) are invertebrates (Balian et al., 2008). However, the species population data available tend to focus on vertebrates. This reflects a global trend where data on invertebrates are generally less comprehensive than for vertebrates or plants (e.g., Troudet et al., 2017; Moreno et al., 2023).

Data gaps relating to freshwater have also been noted in a recent review of progress implementing the GBF (Hirsch et al., 2026). For example, inland water and coastal and marine ecosystems have large data gaps; national targets related to Targets 1, 2 and 12 of the GBF largely focus on terrestrial ecosystems.

We found very little data to measure response indicators for freshwater biodiversity conservation. The main data available were on protected areas, with the best data on freshwater sites linked to Wetlands of International Importance. But Hirsch et al. (2026) found that within the latest national reports to CBD there was insufficient data for disaggregating by inland water protected areas (compared to terrestrial or coastal and marine protected areas) despite it being included as a distinct part of the CBD target regarding protected and conserved area coverage of inland waters.

Although the paucity of response data may be due partly to the fact that actions and policies to reduce pressures and improve biodiversity state and benefits are usually taken at national or sub-national levels, Stephenson & Stengel (2020) identified 33 global data sources for responses, mostly relating to livelihood, economic and moral incentives and conservation designation and planning. The challenge for freshwater is that most of these data sources cannot be disaggregated by biome. As with our study, they also noted that there were no global data for awareness raising, law enforcement and prosecution, and education and training.

Partly due to these data gaps, national reporting on MEA delivery has historically been weak. For example, only 36% of Fourth National CBD Reports contained data (Bubb, 2013) and a review of a representative sample of 21 of the Fifth National CBD Reports found 11 with inadequate data (Koh et al., 2022). Many contracting parties to the Convention on Wetlands do not adequately update their Information Sheet on Ramsar Wetlands (Davidson et al., 2019) and, of the contracting parties reporting to COP14, only 46% (according to their national reports) had completed a National Wetland Inventory, and only 52% provided data on wetland extent for SDG Indicator 6.6.1 (Convention on Wetlands, 2024a). National-level data can also be skewed, with some types of wetland less well covered than others (Bino et al., 2016). Therefore, it is imperative that existing biodiversity data relevant for MEA monitoring are identified and used.

Where can improvements be made to ensure more of the indicators are monitored for freshwater biodiversity?

Many countries lack freshwater biodiversity monitoring programs and have inadequate capacity to conduct standardized data collection or use modern monitoring tools (Jackson et al., 2016; Stephenson et al., 2020; Simaika et al., 2024). The enabling conditions necessary to facilitate freshwater biodiversity conservation and monitoring range from mainstreaming freshwater ecosystem conservation within key existing partnerships, governance instruments and funding mechanisms (e.g.,, Arora et al., 2024), to improving data harmonization and comparability (Lento et al., 2026), to encouraging national wetland inventories (Convention on Wetlands 2025a). Freshwater systems, and especially freshwater invertebrates and plants, need to be integrated into long-term monitoring programs (Barouillet et al., 2024) in order to provide the data needed for biome-specific

MEA monitoring. In turn, ecological research needs to be more explicitly linked to the data needs of the managers and stakeholders of freshwater ecosystems (Hart & Calhoun, 2010). Training and enhancing relevant taxonomic expertise and institutional coordination will be essential (Simaika et al., 2024). However, these broader issues need to be addressed alongside more systemic issues around harmonizing and standardizing biodiversity data systems and processes.

While common definitions and classification for habitats would facilitate data aggregation, different MEAs use different systems. The Convention on Wetlands has traditionally used its Ramsar Classification System for Wetland Type (Finlayson, 2018), which is currently being updated (Convention on Wetlands, 2024b). In contrast, the CBD has adopted IUCN's Global Ecosystem Typology (IUCN, 2026b). At the regional level other classification systems are in use, for example under the EU Habitat or Water Framework Directives. MEA indicators around habitat extent will be difficult to compare and aggregate unless a more harmonized approach can be taken.

A standard typology of data sources is needed if we are to understand and improve monitoring (Stephenson & Stengel, 2020; Kemp et al., in press). There is also a need for collaborative data infrastructures with diverse experts from different disciplines and institutions sharing data and creating integrated databases, as has been seen, for example, with scientific bottom-trawl surveys (Maureaud et al., 2025). Turak et al. (2017) proposed a series of recommendations to improve the measurement of freshwater biodiversity, including the collation of data within global platforms. This study suggests that effort has continued apace, although very few systems that we identified were aimed at aggregating or disaggregating data by biome, which makes it hard to measure freshwater biodiversity.

As data platforms proliferate (Stephenson, 2025; Kemp et al., in press), it remains challenging to assess their content, target audiences and uses. Issues with online data systems and other data sources that still need to be resolved, especially in the context of freshwater, include data duplication, inconsistent or outdated taxonomy (and lack of standardized taxonomic backbones, especially for invertebrates), and spatial inaccuracies (Yiu Cheung & Helfer, 2025; Reygondeau et al., 2026).

Building on earlier recommendations (Stephenson & Stengel, 2020), custodians of online data systems need to specify clearly the expected users (preferably up front on their site's landing page), the types of data available (including biomes, taxa and spatial and temporal scale), the original data sources, the length of the time series available, the frequency (or expected frequency) of data updates, and to what extent data are freely and openly available. Our study further underlines the importance of signaling the types of indicators the data can help measure, preferably with direct reference to specific MEA indicators. Without such information it remains hard for different actors to identify data sources of use to them or to mobilize effort to fill gaps, especially for measuring indicators of use to multiple MEAs and users. This study also underlines the importance of increasing functionality to aggregate and disaggregate data by biome.

Efforts to fill gaps

Efforts are being made to improve the use of existing data and to fill gaps. Some data systems have a network of experts behind them. GBIF (2019) has a freshwater network of data providers that has produced a *Freshwater Data Publishing Guide* (Lento & Schmidt-Kloiber, 2025). It also provides funding to data poor regions to fill some of those freshwater data gaps through its Biodiversity Information for Development program, which has supported several countries and produced outputs such as a checklist of the freshwater fishes of Colombia. The IUCN Secretariat, together with the IUCN Species Survival Commission, leads Red List assessments that feed the IUCN Red List of Threatened Species; these efforts involve training assessors and producing reviews of biome-related taxa (Darwall et al., 2009; Böhm et al., 2021; Sayer et al., 2025). The IUCN SSC Task Force on Global Freshwater Macroinvertebrate Sampling Protocols (GLOSAM) is working towards standardization of sampling protocols to support monitoring of benthic freshwater invertebrates (IHE Delft, 2026). The

Convention on Wetlands secretariat produces guidance materials for contracting parties on conducting National Wetland Inventories (e.g., Convention on Wetlands, 2020, 2025b), and guidance on data management protocols is nearing completion.

Other initiatives to build capacity for freshwater monitoring include development of a Freshwater Biodiversity Observation Network by the Group on Earth Observation Biodiversity Observation Network (GEO BON). UN efforts include the online training developed by the GEMS/Water Capacity Development Center at University College Cork and available on the UNEP eLearning platform (UNEP, 2026), and the UN-Water Integrated Monitoring Initiative for SDG 6.

While much is needed to improve the monitoring of freshwater biodiversity and to report on freshwater-related aspects of the MEA goals and targets, the data that do exist still allow us to gain an overview of status and trends (e.g.,, Feio et al. 2023; Convention on Wetlands, 2025a, Hogan et al., 2025). Given the perilous decline in many wetland habitats and species that these data demonstrate, we should not wait for all the data issues to be resolved before we tackle the pressures on freshwater biodiversity.

Annexes

Table 3. Freshwater-relevant biodiversity indicators across three MEAs.
Table 4. Freshwater-relevant biodiversity metrics.
Table 5. Freshwater-relevant online data systems for biodiversity.

Supplementary Materials

Table S1. MEA indicators scoring 0-2 for relevance to freshwater.
Table S2. Metrics scoring 0-2 for relevance to freshwater.
Table S3. Online data systems scoring 0-2 for relevance to freshwater.
Tables S4 to S7.

- Table S4. Freshwater-relevant pressure indicators from MEAs clustered by IUCN threat category.
- Table S5. Freshwater-relevant state indicators from MEAs clustered by Essential Biodiversity Variable (EBV) class.
- Table S6. Freshwater-relevant response indicators proposed by three MEAs in relation to the IUCN Conservation Actions Classification Scheme (Version 2.0) used in the IUCN Red List of Threatened Species.
- Table S7. Freshwater-relevant indicators common or similar across MEAs.

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