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ENABLING CONSISTENT REPORTING AND MONITORING FOR FRESHWATER (INLAND WATERS) RESTORATION UNDER TARGET 2 OF THE KUNMING-MONTREAL GLOBAL BIODIVERSITY FRAMEWORK

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Contents

Executive summary

Freshwater (inland waters) ecosystems host a disproportionate amount of global biodiversity. They have been extensively degraded and are highly impacted by human activities. These ecosystems provide essential ecosystem services for the survival and well-being of human populations, making their restoration a high priority.

Target 2 of the Kunming-Montreal Global Biodiversity Framework (GBF) aims to bring 30 percent of the total area of degraded terrestrial, inland water, and marine and coastal ecosystems under effective restoration by 2030. Freshwater (inland water) ecosystems are both critical and threatened yet were not highlighted in the sustainable development goals (SDGs) making it important that they be well-represented in the ambitions of the GBF.

Ideally, guidelines for reporting on 'Area under restoration' for inland waters can enable globally consistent reporting that properly incentivizes restoration and monitoring of freshwater (inland waters) ecosystems. Reporting on 'Area under restoration' in such a globally consistent manner is our key to tracking progress.

The objective of these guidelines is to provide a framework for reporting on freshwater (inland waters) ecosystems under Target 2 of the GBF that acknowledges the unique characteristics of freshwater (inland waters) ecosystems. These guidelines are designed for anyone planning, implementing or reporting freshwater (inland waters) restoration.

Reporting on 'Area under restoration' for Target 2 of the GBF should be consistent to the degree possible with related reporting frameworks to provide ecological coherence and data interoperability as well as to minimize reporting burden to countries and allow clear conclusions about progress.

The proposed definition of 'Area under restoration' for freshwater (inland waters) ecosystems is "The area over which the restoration underway is expected to provide any of the outcomes identified under Target 2 of the GBF." These desired outcomes include enhanced biodiversity, enhanced ecosystem functions and services, enhanced ecological integrity, and enhanced connectivity[1].

Thinking ahead to monitoring is important because areas reported under restoration will naturally be those areas that are monitored in the future. Scientifically sound monitoring is essential for ensuring the ecological effectiveness of the GBF.

The choice of monitoring indicators is crucial in guiding restoration activities and in providing actionable information on the health of freshwater ecosystems. A large number of indicators and global data sets exist to complement and enhance tracking progress on Target 2.

[1] See the following link for more information, please see https://www.cbd.int/gbf/targets/2

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Key messages

- Freshwater restoration encompasses a wide range of activities and differs from terrestrial or marine restoration in that it generally requires an understanding of catchment or hydrologic basin (watershed) processes.

- Because of the interconnectedness of watersheds and watershed processes, the area under restoration is most often much larger than the area of on-the-ground (or in-the-water) activities.

- Restoration reporting, watershed assessments, inland fisheries risk assessments, and freshwater (inland waters) restoration monitoring are linked. Where possible, the same indicators can be used. A large amount of relevant geospatial data exist for supporting these efforts.

Kunming-Montreal Global Biodiversity Framework (GBF) – Target 2

Restore 30 percent of all degraded ecosystems

Ensure that by 2030 at least 30 percent of areas of degraded terrestrial, inland water, and marine and coastal ecosystems are under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity.

Notes on terminology

1. The terms "watershed", "catchment", "basin" and "hydrologic basin" all refer to the same concept and are generally used interchangeably. We primarily use watershed in this document. Theoretically, a watershed can be defined for any point, but it is easiest to define a watershed for points along a stream network. The watershed for a point encompasses all the area from which water drains to that point. A watershed can therefore be any size. The watershed defined by the mouth of the Amazon River is massive, covering many countries. The watershed of a little stream is, generally, very small. Watersheds are nested, with smaller watersheds of streams inside larger and larger watersheds.

2. The authors retain the use of the term "freshwater (inland waters) ecosystems" throughout to ensure that the text remains tightly connected to both the large body of science surrounding freshwater ecosystems as well as to the reporting agreements of the GBF. The authors understand that some areas generally imagined under the phrase "freshwater" may by saline. Various terms are used under different conventions and by different disciplines to refer to these critical ecosystems. We intend that this somewhat long phrase continuously reminds readers of the need for a multidisciplinary approach and compatibility across reporting processes and conventions.


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1.
FRESHWATER (INLAND WATERS) RESTORATION FOR A SUSTAINABLE FUTURE

Freshwater (inland waters) host a disproportionate amount of global biodiversity

Freshwater (inland waters) ecosystems cover less than 2 percent of Earth's surface yet support 12 percent of all known species (Garcia-Moreno *et al.*, 2014).

They are home to more than 140 000 non-microbial species (i.e. fungi, plants, invertebrates, and vertebrates) and about 50 percent of all fish species on Earth (Albert *et al.,* 2020; Reid *et al.,* 2019).

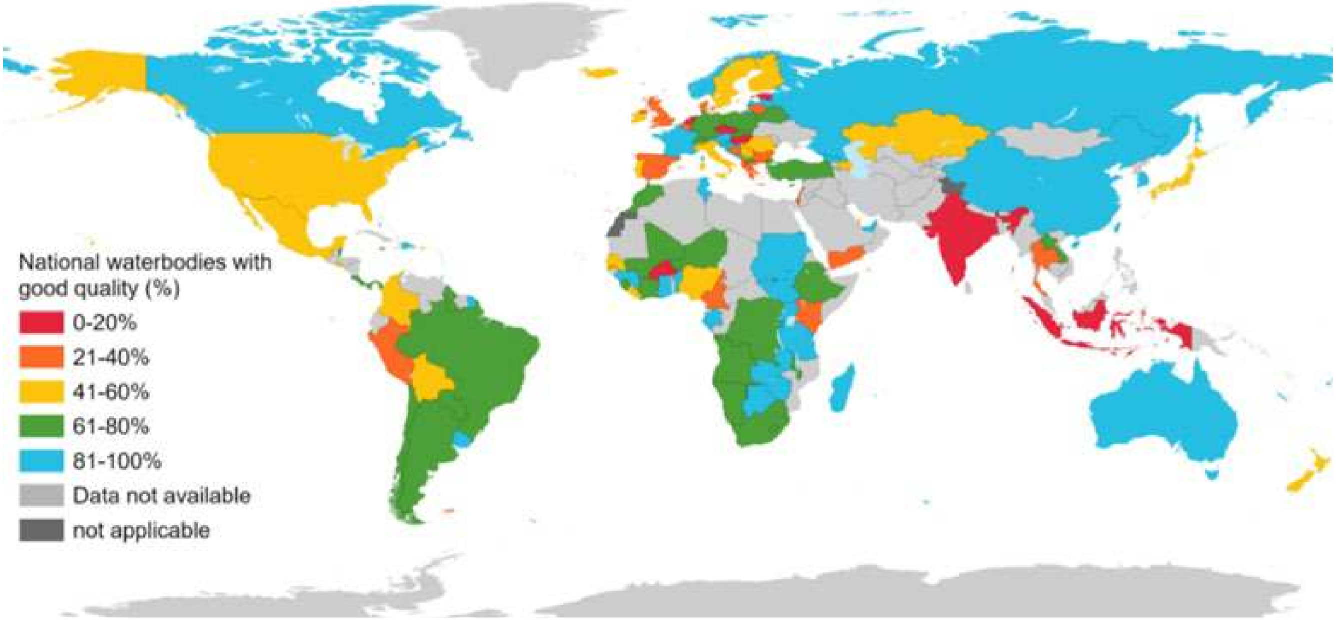
Freshwater (inland waters) and associated biodiversity have been extensively lost and are highly impacted by human activities

Freshwater (inland waters) vertebrate populations have declined, on average, by 85 percent since 1970 (WWF, 2020). Estimates of inland wetland loss remain uncertain; varying from an estimate of 21 percent loss since 1700 (Fluet-Chouinard *et al.,* 2023) to 87 percent loss over the last 300 years (Davidson, 2014). Human impacts to freshwater (inland waters) ecosystems are vast. For example, humans divert > 10 000 km^3 of fresh water per year for agriculture, industry and domestic uses, an amount equivalent to about a third of the average flow of all continental waters discharging to the sea. Persistent threats include overexploitation, water pollution, flow modification, altered thermal regimes, habitat destruction, and invasion from exotic species (Dudgeon *et al.,* 2006). Emerging threats include climate change, infectious diseases, new contaminants, engineered nanomaterials, microplastics, light and noise, and changing water chemistry (Reid *et al.,* 2018).

Only 40 percent of the surface water bodies assessed under the European Union Water Framework Directive were in good or high ecological status for the period 2010-2015 (EEA, 2018). And, based on data collected in 2023, only 56 percent of all monitored water bodies worldwide were classified as having good ambient water quality (UNEP, 2024) (Figure 1).

Additionally, 2024 data presented in the SDG 6.6.1 portal, reveal alarming trends in the degradation of water-related ecosystems. With the use of satellite-based monitoring tools that have now become indispensable for global tracking, SDG 6.6.1 findings indicate that 50 percent of countries report degraded ecosystems. There is scarce information in some countries making it difficult to estimate exactly how many ecosystems are severely deteriorated.

Figure 1. Global values of Sustainable Development Goals indicator 6.3.2



Notes:

SDG indicator 6.3.2 assesses the proportion of a country`s water bodies (rivers, lakes and aquifers) having good ambient water quality, taking into account data on conductivity, acidification, nitrogen, phosphorus and oxygen. https://gemstat.org/2024-sdg-632/

Refer to the disclaimer on page ii for the names and boundaries used in this map. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined.

Source: UNEP. 2024. GEMStat: New report on UN SDG indicator 6.3.2 released [accessed on 27 January 2025] https://gemstat.org/2024-sdg-632/

Freshwater (inland waters) ecosystems provide a variety of ecosystem services for the survival and well-being of human populations

These services include provision of clean drinking water, direct food production (i.e. fisheries), water quantity regulation (e.g. groundwater recharge and buffering from flood events), water quality regulation (e.g., nutrient and sediment transport), climate regulation, recreational opportunities and cultural values (Brauman *et al.*, 2007; European Commission, 2020; Gleick, 2014; Hallouin *et al.*, 2018; Postel and Thompson, 2005; Wilson and Carpenter, 1999). A global meta-analysis, albeit dominated by research from the United States, indicated that the value of ecosystem services provided by lakes ranges from USD 106-140 (in 2010 dollars) per respondent per year (Reynaud and Lanzanova, 2017).

More recently, WWQ Ecosystems (2023) estimate the global value of ecosystem services from all natural lakes at USD 3.1 trillion per year and from constructed reservoirs at USD 0.3 trillion per year.

The importance of inland or freshwater ecosystems are mentioned specifically, under SDG Target 15.1 "By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services." Costanza *et al.* (2014) estimate that meeting the UN SDGs would increase by 18 percent the value of freshwater ecosystem services by 2050.

There are many benefits of restoring freshwater (inland waters) ecosystems

In addition to economic benefits from the ecosystem services described above there are strong linkages to human well-being and biodiversity. The benefits include improved water quality that can translate into increased biodiversity across ecosystems and improved human health for some of the world's most vulnerable populations. More than 50 percent of the world's population lives closer than 3 km to a surface freshwater body (Kummu *et al.,* 2011).

Freshwater restoration can build resilience in food systems via sustainable management of nutrients (Brownlie *et al.,* 2022) and water for agriculture and fishing activities. Fishing activities may include community fishing from lakes and rivers, commercial freshwater fishing, and also aquaculture, with freshwater fish accounting for 75 percent of global edible aquaculture by volume (Naylor *et al.,* 2021). Additionally, there are positive impacts on marine fisheries with 77 percent of marine catch linked to river flows for at least part of their life history (Broadley *et al.,* 2022). In addition to direct ecological benefits, restoring freshwater ecosystems can contribute to climate change mitigation efforts. For instance, rehabilitating wetlands and peatlands can reduce carbon emissions while enhancing their ability to sequester carbon, contributing to global climate goals (Nahlik and Fennessy, 2016; FAO, 2014).

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2.
FUNCTIONING OF FRESHWATER (INLAND WATERS) ECOSYSTEMS

Freshwater (inland waters) ecosystems are diverse and nested within watersheds

Freshwater (inland waters) ecosystems include streams, rivers, floodplains, lakes, ponds, delta areas and more (Table 1). They are highly dynamic and productive environments. There are several typologies and classifications of freshwater ecosystems proposed at the global level, e.g. IUCN Global Ecosystem Typology V2.0 (GET) (Keith *et al.*, 2020), FAO Land Cover Classification System, EUNIS.

The GET is a comprehensive classification framework for Earth's ecosystems that integrates functional and compositional features and classifies inland freshwater ecosystems into 6 main biomes, representing 33 functional groups (Table 1). The ad-hoc technical expert group of the Kunming-Montreal Global Biodiversity Framework (GBF) has suggested the GET as an underlying typology to disaggregate the area-based targets, such as the headline indicator for Target 2, 'Area under restoration' (CBD/SBSTTA/26/L.10).

Table 1. Inland freshwater biomes and functional groups considered in the International Union for Conservation of Nature (IUCN) Global Ecosystem Typology (GET)

Realm	Biome	Ecosystem functional group
F Freshwater	F1 Rivers and streams biome	F1.1 Permanent upland streams
		F1.2 Permanent lowland rivers
		F1.3 Freeze-thaw rivers and streams
		F1.4 Seasonal upland streams
		F1.5 Seasonal lowland rivers
		F1.6 Episodic arid rivers
		F1.7 Large lowland rivers
	F2 Lakes biome	F2.1 Large permanent freshwater lakes
		F2.2 Small permanent freshwater lakes
		F2.3 Seasonal freshwater lakes
		F2.4 Freeze-thaw freshwater lakes
		F2.5 Ephemeral freshwater lakes
		F2.6 Permanent salt and soda lakes
		F2.7 Ephemeral salt lakes
		F2.8 Artesian springs and oases
		F2.9 Geothermal pools and wetlands

Realm	Biome	Ecosystem functional group
		F2.10 Subglacial lakes
	F3 Artificial wetlands biome	F3.1 Large reservoirs
		F3.2 Constructed lacustrine wetlands
		F3.3 Rice paddies
		F3.4 Freshwater aquafarms
		F3.5 Canals, ditches and drains
TF Terrestrial - Freshwater	TF1 Palustrine wetlands biome	TF1.1 Tropical flooded forests and peat forests
		TF1.2 Subtropical/temperate forested wetlands
		TF1.3 Permanent marshes
		TF1.4 Seasonal floodplain marshes
		TF1.5 Episodic arid floodplains
		TF1.6 Boreal, temperate and montane peat bogs
		TF1.7 Boreal and temperate fens
SF Subterranean-Freshwater	SF1 Subterranean freshwaters biome	SF1.1 Underground streams and pools
		SF1.2 Groundwater ecosystems
	SF2 Anthropogenic subterranean freshwaters biome	SF2.1 Water pipes and subterranean canals
		SF2.2 Flooded mines and other voids

Source: Keith, D.A., Ferrer-Paris, J.R., Nicholson, E. and Kingsford, R.T., eds. 2020. The IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups. Gland, IUCN.

The GET can be related to more detailed national and sub-national ecosystem classes (e.g. South Africa, Australia). Australia, for example, classifies inland aquatic ecosystems in the National Vegetation Information System with mapping of lacustrine, palustrine, riverine, and intertidal wetland types at the state-level (Department of Environment and Science, 2023). In Colombia, a hierarchical classification has been proposed, organized into four levels (system, macroregion, subsystem, and class), which allows categorization of wetlands in 89 macrohabitats across marine-coastal, inland, and anthropogenic systems (Ricaurte *et al.*, 2019).

Threats to freshwater (inland waters) ecosystems emanate from terrestrial activities across the watershed

Because of tight relationships between terrestrial conditions within catchments, e.g. basins or watersheds, and freshwater (inland waters) ecosystems, these terrestrial conditions across catchments are a key driver of what goes on within river networks and in associated wetlands, lakes and reservoirs. Accordingly, land degradation (e.g. deforestation, agricultural intensification, and wetland drainage) is a major driver of the changes in freshwater condition; pollution from agriculture (e.g. pesticides and nutrients), industry (e.g. metals and petroleum products, pharmaceutical substances), mining (e.g. metals) and urbanization (e.g. sewage, plastics) also all play a major role in their degradation (Allan, 2004; IPBES, 2018). Stormwater discharge, for example, presents a global challenge to freshwater systems associated with indirect human actions across terrestrial systems through toxic substances in tire dust (Challis *et al.,* 2021) and microplastics (Talbot and Chang, 2022).

Direct alterations of and instream changes to freshwater habitats are also critical drivers of freshwater habitat degradation and species loss. Physical alterations include built infrastructure such as dams, levees, and culverts which fragment freshwater systems as well as rip-rap or other bank stabilization measures which prohibit natural bank habitats and meandering. Sediment or cobble mining and water withdrawals are additional examples of direct habitat alterations which degrade freshwater habitats. Non-native hard hooved animals, such as feral pigs and cattle, also cause degradation.

Freshwater (inland waters) restoration science is an established discipline with decades of experience

Freshwater (inland waters) restoration has been part of ecosystem management for decades (Jansson *et al.,* 2007; Palmer *et al.,* 1997) and it has a fundamental role to play in accelerating restoration (e.g. Wohl *et al.,* 2015). Eutrophication management in lakes, for example, has been active since the 1940s (Spears *et al.,* 2022). With this technical report, we aim to focus that longstanding knowledge into guidance on reporting on the headline indicator for Target 2 of the GBF, 'Area under restoration', for freshwater (inland waters) ecosystems. The guidance here builds on a wide range of process-based restoration guidelines (e.g. Kupilas *et al.,* 2024, Wheaton *et al.,* 2019).

The UN Decade on Ecosystem Restoration, from 2021-2030, is a proposal for action by over 70 countries from all latitudes that calls for the protection and revival of ecosystems across the world for the benefit of people and nature. Of the currently most visible or flagship restoration projects, only a few focus specifically on river basins and freshwater ecosystems, e.g. Pakistan's Living Indus initiative. Combined with the ambitions of Target 2, restore 30 percent of all degraded ecosystems, of the GBF, and the recent country-led Freshwater Challenge, there is now a tremendous opportunity to bring global expertise, experience, and ambition to the restoration and monitoring of freshwater (inland waters) ecosystems globally.

3.
FRESHWATER (INLAND WATERS) RESTORATION AND THE KUNMING-MONTREAL GLOBAL BIODIVERSITY FRAMEWORK

The Kunming-Montreal Global Biodiversity Framework (GBF) supports four high-level goals: protect and restore; prosper with nature; share benefits fairly; and invest and collaborate.

Target 2 of the GBF aims to bring 30 percent of the total area of degraded terrestrial, inland water, and marine and coastal ecosystems under effective restoration by 2030.

Results and reporting are likely to be disaggregated by three ecosystem types, depending on country-level reporting mechanisms and the GBF monitoring framework. Restoration of inland waters under Target 2 should contribute to the four specific outcomes sought under Target 2: enhanced biodiversity, enhanced ecosystem functions and services, enhanced ecological integrity, enhanced connectivity. All actions undertaken to reach Target 2 should take into account the specific considerations for implementation identified in Section C of the GBF such as the important role of indigenous peoples and local communities, differing value systems, human rights, gender, and ecosystem approaches. Actions should be based on scientific evidence and traditional knowledge and practices, recognizing the role of science, technology and innovation. Achieving the firm restoration principle of "do no harm" is possible if it is embedded from the beginning into the design of reporting and monitoring.

Strong freshwater (inland waters) ecosystem links exist across international frameworks. The Convention on Wetlands (2024a) describes the critical role of wetlands in achieving the 23 targets of the GBF and provides guidance on incorporating the role and importance of wetlands and into National Biodiversity Strategies and Action Plans (NBSAPs) and embedded key actions.

To date, freshwater ecosystems have not been well-represented in the national restoration targets related to Target 2 of the GBF. Preliminary analysis of submitted national targets (n=213 in total, database extracted on 28 August 2024) finds few with quantitative targets focused specifically on freshwater (inland water) ecosystems. Potential reasons for the absence of freshwater (inland waters) ecosystem targets include an absence of local data and the complexity of freshwater (inland waters) ecosystem assessments. An example of a national target specially focused on fresh water is that from Hungary, "Restoring at least 34 000 hectares of wetlands and preventing their further degradation." France has also included the creation of a national park with at least 50 000 ha of wetland in its plan (Convention on Wetlands, 2024a). In Colombia, the Ministry of Environment has recently made an investment for the ecological restoration of the Mojana wetland complex to include the rehabilitation of channels and the reconnection of the Cauca River. Related positive examples are also in the restoration targets of some countries receiving funds from the Global Environmental Facility 8 Ecosystem Restoration Integrated Program aiming at restoring 1.8 million hectares of crucial ecosystems, including wetlands. South Africa's goal, for example, is to use a transdisciplinary approach to restore about 50 000 ha (direct restoration and improved practices) of peatlands and their surrounding catchments.

It is essential that freshwater systems be well-represented in the ambitions under the GBF as these critical and threatened ecosystems were not well-highlighted in the SDGs (Stoakes *et al.,* 2024; Lynch *et al.,* 2020).

The Freshwater Challenge is a country-led initiative that aims to support the implementation of Targets 2 and 3 of the GBF for inland waters through integrating inland waters in national restoration targets, substantiating what is needed in terms of restoration and protection and accelerating investment to reach these targets. Launched in March 2023 at the United Nations Water Conference, the Freshwater Challenge aspires to restore 300 000 km of degraded rivers and 350 million hectares of degraded wetlands by 2030. As of December 2024, 50 countries and the European Union were now members of the Challenge. The Freshwater Challenge and the Global Environment Facility (GEF) 8 ERIP also have a partnership to support knowledge sharing. The GEF 8 ERIP aims to restore 4.3 million hectares of crucial ecosystems such as forests, mangroves, wetlands, peatlands, and grasslands across 20 countries: Angola, Brazil, Cambodia, Chad, Côte d'Ivoire, Democratic Republic of the Congo, Haiti, Madagascar, Mali, Mauritania, Mexico, Mozambique, Nepal, Peru, Rwanda, São Tomé and Príncipe, Sierra Leone, South Africa, Uzbekistan, and Viet Nam. These activities can provide case studies for reporting of freshwater (inland waters) ecosystem restoration. Implementation of actions under Target 2 for freshwater (inland waters) ecosystems can also support the fulfillment of the UN Resolution on The Human Right to a Clean, Healthy and Sustainable Environment (A/HRC/RES/48/13). Ideally, guidelines for reporting on 'Area under restoration' for inland waters can enable globally consistent reporting that properly incentivizes restoration and monitoring of freshwater (inland waters) ecosystems. Costs for freshwater restoration such as floodplain restoration or dam removal are relatively fixed given particular environmental, engineering and regulatory conditions; what can be incorrectly assumed is that the area under restoration is only the area within which these actions occur. In fact, the reason these types of actions are so valuable is that the area enhanced often extends well beyond the site of intervention. Floodplain restoration, for example, can influence biodiversity far upstream, downstream, and even to the side of where on-the-ground (or in-the-water) activities occur. By incorporating this understanding of the real extent over which benefits may occur, the cost per unit area restored and the social and ecological benefits accrued can be more accurately estimated to encourage investment.

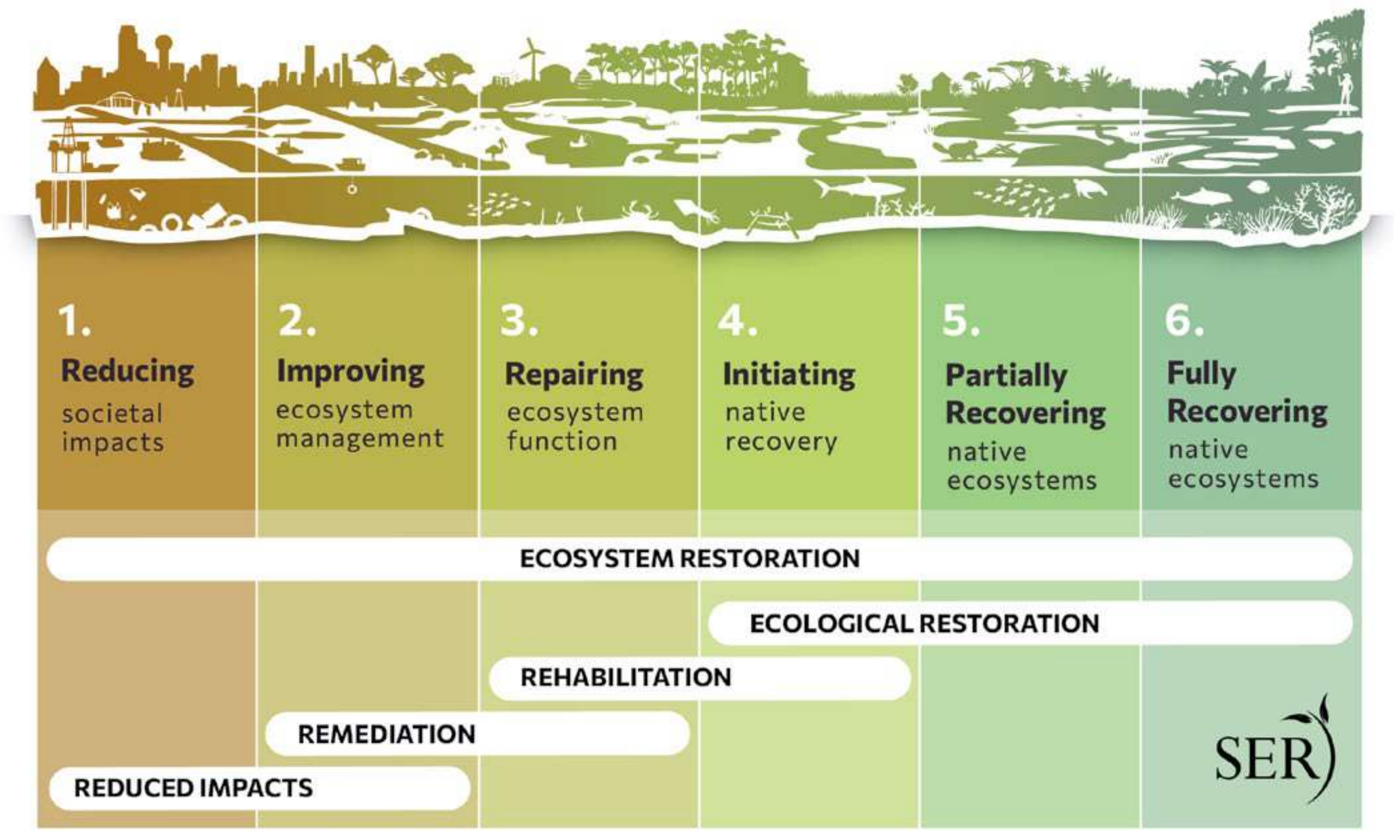
Proper reporting and therefore enabling and incentivizing of freshwater restoration is a key to moving efficiently toward a sustainable future.

4.
FRESHWATER RESTORATION AND HOW IT DIFFERS FROM TERRESTRIAL OR MARINE RESTORATION

Freshwater (inland waters) restoration encompasses a wide range of activities along the restorative continuum

Activities may include, for example, re-engineering or removing a small culvert to enable fish passage that opens a huge amount of upstream habitat to migratory fishes or planting papyrus and other vegetation to reduce stream temperatures and the flow of fine sediments far downstream. It can include activities which appear to be primarily terrestrial in nature such as forest road decommissioning or coordinated suites of activities over large spatial scales such as for nutrient pollution management in lake catchments. A restoration intervention typology for terrestrial ecosystems has been produced by IUCN. Although extensive lists and descriptions of freshwater (inland waters) restoration activities are available, we are not aware of a similar internationally agreed typology or catalogue.

Figure 2. The restorative continuum



Note: Restorative activities for terrestrial, inland waters, or coastal and marine ecosystems can aim for a wide range of impacts, from reducing societal impacts to fully recovering native ecosystems.

Source: FAO, SCBD and SER. 2024. Delivering restoration outcomes for biodiversity and human well-being — Resource guide to Target 2 of the Kunming-Montreal Global Biodiversity Framework. Rome, Montreal, Canada and Washington, DC. https://doi.org/10.4060/cd2925en

Box 1a. Simplified watershed and initial conditions

Note: This simplified watershed displays pre-restoration conditions and how everything inside the watershed is inexorably linked by the flow of water. Colour of the stream or river is intended to indicate water quality with lighter colors indicating poorer conditions which might result from degraded land or forest conditions. Key flow pathways beyond the flow of water include the movement of sediment and the flows of trophic, physical and thermal energy. While most flows are downstream, upstream flows also exist, particularly those facilitated by fish movement which can bring nutrients and even riparian tree seeds far upstream.

For more on these flows, working at the watershed scale and fundamentals of watershed ecology and monitoring, see the eLearning "Resilient Rivers: watershed-based management of forests, freshwater, and inland fisheries' which is freely available.

Source: Authors' own elaboration.

Effective freshwater (inland waters) ecosystem restoration generally requires an understanding of watershed-scale processes

Everything inside a catchment is inexorably linked by the flow of water and thus of material and energy (Box 1). Compared to restoration of terrestrial ecosystems, freshwater (inland waters) ecosystem restoration activities require an understanding of particular processes such as aquatic species distributions and life histories, water chemistry, biogeochemical cycles, and natural flow regimes. To achieve successful freshwater (inland waters) ecosystem restoration, it is imperative to consider conditions across entire catchments to reduce major stressors. Restoration actions most often target the flow of water (amount and timing), biota, sediment, nutrients, chemicals or energy across watersheds. For example, a global assessment of lake restoration of 179 restoration practitioners spanning 65 countries indicated that "the most effective and widely used restoration measures target nutrient loading (both catchment and in-lake) while hydrological modifications and the implementation of nature-based solutions are used to a lesser extent" (Poikane *et al.,* 2024).

Freshwater (inland waters) restoration generally aims to restore one or more degraded key ecological attributes

Ecological attributes essential for freshwater systems include hydrologic regime (timing, duration, magnitude, frequency), connectivity (longitudinal, lateral, vertical, temporal), water quality, habitat complexity and biotic composition (Karr, 1991; Karr, 1999). The magnitudes of natural flows, for example, are usually highly variable and often fluctuate on the order of minutes, days, and seasons. In cases where alteration of the hydrologic regime is the limiting factor in freshwater ecosystem health, restoration would then focus on returning the natural or a desired pattern of timing, magnitude and/or duration of water flows. The desired and possible patterns of water flow generally depend on elements of the hydrologic cycle including local climatic conditions, e.g., precipitation and temperature, as well as highly spatially variable factors such as condensation, evaporation, and infiltration (particularly groundwater) (Hallouin *et al.,* 2018; Shillman and Rodda, 2003).

Water depth is an additional consideration for many freshwater (inland waters) ecosystem restoration activities

Unlike most terrestrial ecosystems, restoration of freshwater (inland waters) ecosystems involves a consideration of fluctuations in depth as well as temporal and spatial variability. In lakes, depths are sometimes measured in thousands of meters, as in Lake Baikal in the Russian Federation (around 1 741 m), or Lake Tanganyika in East Africa (around 1 471 m) (Shiklomanov and Rodda, 2003). Groundwater and even hyporheic water flowing through interstitial spaces with unique residence times are additional and essential considerations related to depth.

Rivers are generally linear with directional flows and desired conditions that shift along the river continuum

For river systems, directionality of flows and movements is an important consideration; upstream activities affect downstream conditions via the flows of water, sediment and energy. Downstream activities influence species distributions in upstream areas via enhanced or limited migration corridors. Natural or desired conditions also shift predictably along river gradients with stronger ties between terrestrial and aquatic ecosystems in both upstream and far downstream areas (Vannote *et al.*, 1981). For river systems, restoration activities are often measured in km or length rather than km^2 or area although benefits can be understood to accrue across watersheds.

Box 1b. Simplified watershed and restored conditions

Notes: A set of freshwater restoration projects and their outcomes (as compared to conditions pictured in Box 1a) are illustrated in a watershed context. Details of on-the-ground and in-the-water activities that might be hypothetically included in these seven example restoration projects are provided in Table 3 and possible 'areas under restoration' for reporting purposes are displayed in Box 1c.

Source: Authors' own elaboration.

5.
GUIDING PRINCIPLES FOR MOVING FORWARD IN REPORTING ON 'AREA UNDER RESTORATION' FOR TARGET 2 OF THE GLOBAL BIODIVERSITY FRAMEWORK

Reporting on 'Area under restoration' in a globally consistent manner is our key to tracking progress. A resource guide to Target 2 has been developed by FAO, the Secretariat of the Convention on Biological Diversity (SCBD) and the Society for Ecological Restoration (SER) (FAO, SCBD SER, 2024).

Building on the CBD's Short-Term Action Plan on Ecosystem Restoration (STAPER), the resource guide compiles resources to support countries as they implement the target across ecosystems, including inland water ecosystems. These resources include a general methodology and guidance for monitoring and reporting on indicator 2.1, 'Area under restoration'. The guiding principles proposed here for freshwater (inland waters) ecosystems are consistent with this existing framework.

Guiding principles for reporting include consistency in definitions, transparency in data processing and management, and interoperability across reporting processes and platforms. Reporting processes should both enable country leadership in reporting and minimize the reporting burden of countries through coordination, clear documentation, and simplicity wherever possible.

Reporting processes should build on and embody the goals of Target 2 and the vision of the GBF including the value of biodiversity, the maintenance of ecosystem services, sustaining a healthy planet and delivering benefits essential for all people.

The GBF should be implemented based on the ecosystem approach and therefore reporting also takes an ecosystem perspective. For freshwater (inland waters) ecosystems, an ecosystem perspective implies a watershed perspective that considers the relationships of ecosystem components linked by the flow of water. This watershed perspective underscores the importance of the difference between the area of on-the-ground actions and the area under restoration. The 'Area under restoration' is the area over which biodiversity, ecosystem functions and services, ecological integrity, and ecological connectivity are expected to be enhanced. Hydrological connectivity is the focus of ecological connectivity for freshwater (inland waters) ecosystems, supporting material and energy delivery to and exchange across waterways within the watershed.

6.
LINKS TO RELATED REPORTING PROCESSES

Reporting on ‘Area under restoration’ for Target 2 of the GBF should be consistent to the degree possible with related reporting frameworks to provide ecological coherence and data interoperability as well as to minimize reporting burden to countries and allow clear conclusions about progress.

FAO and IUCN, for example, have signed a joint agreement for data sharing to facilitate reporting on GBF Target 2. By working together, IUCN and FAO will better align the Restoration Barometer and the Framework for Ecosystem Restoration Monitoring (FERM) with Target 2 reporting requirements and facilitate data sharing between the two platforms.

The organizations will also be able to deliver technical training and capacity support while gathering stakeholder feedback in pilot countries, all while maintaining strict data quality control measures.

Within the GBF, reporting on Target 2 is closely tied to many of the other targets and specifically with reporting on Target 3, to conserve 30 percent of terrestrial, inland waters, and marine and coastal ecosystems. Ideally reporting guidance for these two targets is conceptually coherent and parallel definitions are used wherever possible. Reporting on progress toward Target 2, for example, will likely be disaggregated by areas under effective conservation as reported under Target 3. Reporting processes for the Aichi Biodiversity Targets may also be considered as Target 2 addresses issues that were previously addressed by Aichi Biodiversity Target 15.

Reporting on Target 2 for freshwater (inland waters) ecosystems is closely connected to reporting on many of the SDG indicators for Goal 6, Ensure availability and sustainable management of water and sanitation for all. In particular, reporting on Target 2 for inland waters should be coherent with work already accomplished for reporting on indicator 6.6.1: Change in the extent of water-related ecosystems over time, building on the same conceptual framework and data sources where possible. Leveraging SDG 6.6.1 data methodologies, which include satellite-based monitoring of ecosystem extent and health, can enhance consistency between frameworks and indicators for freshwater (inland waters) ecosystem restoration under the GBF. Reporting on Target 2 is clearly conceptually related to work on Goal 15, target 15.1: By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements. Note however that the two current indicators are not likely to build on the same data or conceptual frameworks.

Target 2 will consider restoration actions that mitigate the effects of climate change on biodiversity as well as potentially identifying those measures that reduce greenhouse gas emissions from polluted ecosystems, for example, through the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. As such, guidelines on definitions and principles for reporting will have implications for how climate change related restoration for inland waters is targeted, tracked and reported across National Biodiversity Plans, Nationally Defined Contributions and National Adaptation Plans related to the Paris Agreement.

7.
DEFINITION OF 'AREA UNDER RESTORATION' FOR REPORTING ON TARGET 2 OF THE GLOBAL BIODIVERSITY FRAMEWORK

The definition of area under restoration for freshwater (inland water) ecosystems is “The area over which the restoration underway is expected to provide any of the outcomes identified under Target 2.”

These desired outcomes include enhanced biodiversity, enhanced ecosystem functions and services, enhanced ecological integrity, and enhanced connectivity.

The application of this definition allows and empowers reporters to include the full area expected to be positively impacted by restoration activities and moves us forward toward global coherence in reporting. As described above, for freshwater (inland waters) ecosystems, the areas which are hydrologically connected and which benefit from the intervention are often dramatically more extensive than the area where activities occur. Take, for example, an expensive dam removal project which aims to enhance biodiversity, ecosystem functions and services, ecological integrity and connectivity not in the area where the dam is removed but across sub-watersheds far upstream and downstream. The principles underlying this definition are parallel to those applied by IUCN for the Restoration Barometer. For the Restoration Barometer, IUCN has defined the amount of land under active restoration as “the area (in hectares) where functionality (ability to provide ecosystem goods and services) has been improved by restoration (not only area of direct intervention)”.

The Framework for Ecosystem Restoration Monitoring (FERM)

The FERM was developed and launched in 2022 through the collaborative efforts of the United Nations Decade on Ecosystem Restoration and the FAO-led Task Forces on Monitoring and Best Practices. Originally designed as the monitoring framework of the UN Decade, it enables restoration stakeholders and national entities to share information on restoration progress and contributions at different scales. It has been enhanced to support countries in reporting on ‘Area under restoration’ for Target 2. The FERM aims to harmonize and collect area-based data on ecosystem restoration projects and programs, and to enable interoperable data exchange with other platforms. It currently includes a registry of restoration initiatives, a geospatial tool for visualizing restoration data, and a search engine for consulting good practices on ecosystem restoration. Based on the recommendations of the CBD Parties, the FERM geospatial platform will be regularly enhanced to meet the monitoring and reporting needs of the United Nations Decade on Ecosystem Restoration and Target 2 of the GBF.

8.
GUIDANCE FOR REPORTING 'AREA UNDER RESTORATION'

Here we provide general conceptual guidance for reporting on Target 2, 'Area under restoration', that takes into account the definition above as well as the the structure and function of freshwater (inland waters) ecosystems and enables reporting at the local to national scale in a relatively consistent manner as well as global data aggregation.

We aim for simple, inclusive and non-prescriptive guidance that moves us forward in honestly quantifying restoration of freshwater (inland waters) ecosystems and enables global coherence in reporting. We encourage consideration of each activity within a restoration project and the scale of the restoration activity which may often be related to the location in the watershed and to the size of that watershed. Additionally, because ecological services from freshwater (inland waters) depend on interlinkages between surface and sub-surface water, both should be considered in identifying area restored for flowing and non-flowing waters.

Providing exact directions to quantify the area restored for each type of restoration activity in each type of ecosystem (and at each point in a watershed) is an impossible level of detail at this stage. Instead, we are providing guidance on the principles that a restoration practitioner should apply in estimating the area under restoration. These principles should be coherent across restoration types, ecosystem types, project scales, national contexts and national capacities. Examples for illustrative purposes only are provided in Box 1c and Table 3.

In all cases, we encourage consideration of ecosystem processes across watersheds and the four desired outcomes of the Target 2 of the GBF: biodiversity, ecosystem functions and services, ecological integrity, and ecological connectivity. The estimation of area enhanced is often a somewhat subjective measure as compared to area of on-the-ground activity. However, reporting only area of on-the-ground activities runs the risk of incentivizing projects that take place across large spatial extents, but which don't necessarily lead to large-scale ecosystem benefits in terms of the enhancement goals under Target 2.

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For flowing waters, defined as flow on the order of seconds to hours:

The area under restoration is the aggregate of three types of potential areas:

1. the direct area of on-the-ground (or in-the-water) restoration activity;
2. the upstream area expected to benefit from improved biodiversity (due to improved connectivity most often);
3. the downstream and lateral areas expected to see enhanced biodiversity or enhanced water quality (bio-physicochemical parameters, e.g. algae, bacteria, electrical conductivity, temperature, total suspended solids, nutrient and heavy metal concentrations) and flows of water, wood, and sediment (altered in such a way as to move toward a less disturbed state).

The reason for describing this in terms of altered material flows is that these types of changes can be reasonably estimated from a restoration plan and it is these types of changes that initiate cascades of impacts, e.g. reductions in turbidity leading to improved oxygenation of a cobble substrate enabling increased diversity and quantity of macroinvertebrates which support aquatic and terrestrial trophic food webs, increasing biodiversity. These cascades of impacts underlie the four desired outcomes of Target 2 of the GBF.

Within FERM, it will be possible to identify the area under restoration for freshwater (inland waters) ecosystems in three ways:

1. to upload a shape file based on these guiding principles;
2. to draw the area by hand based on these guiding principles;
3. or to select sub-basins using HydroSHEDS data layers at the relevant scale. In some cases, these might be hydrobasins at the smallest available level and, in other cases, larger hydrobasins would better reflect the full area where enhanced conditions as described above are expected.

Incorporating this functionality into FERM is underway.

For non-flowing waters, defined as flow on the order of weeks to years:

The area under restoration is the aggregate of three types of potential areas:

1. the direct area of on-the-ground (or in-the-water) restoration activity;
2. the surface area of the wetland or waterbody being restored. If a small wetland or waterbody, consider the entire area of that unit (assuming the outcomes of biodiversity, ecosystem services, ecological integrity, and connectivity are expected to improve across most or all of the area). If a larger wetland or waterbody, identify specific subsections where improvements in the four outcomes are anticipated.
3. any nearby aquatic units or sub-watersheds that are connected through surface flows or likely connected through subsurface flows or that are likely to benefit from the restoration activity in terms of any of the four desired outcomes of the GBF.

Within FERM, it will be possible to identify the area under restoration for freshwater (inland waters) systems in three ways:

1. upload a shape file based on these guiding principles,
2. draw the area by hand based on these principles, or use information from the Global Lakes and Wetlands Database Version 2 (GLWD V2), select units from HydroLAKES, or select sub-basins as above.

Incorporating this functionality into FERM is underway.

For flows on the order of hours to weeks, reporters can select or combine approaches above based on restoration type, ecosystem context and desired outcomes.

Box 1C. Simplified watershed and reporting on 'Area under restoration'

Notes: For each of the seven example restoration projects in Box 1B, the areas over which they might be expected to enhance biodiversity, ecosystem functions and services, ecological integrity, and connectivity are highlighted. These areas would be reported as the "Area under restoration." For any particular suite of restoration activities, the exact area over which desired outcomes are expected to be enhanced will be watershed-specific. We note that these are only example restoration projects and examples of how the guidance in this document could be interpreted in particular contexts. In Table 3, we imagine where along the restorative continuum (Figure 2) each project might occur, what activities might be included and how an expert might delineate the area under restoration, noting again that these are examples and that other degrees of restoration for the same project or other methods of delineation are possible. Imagining these example restoration projects, it is clear that there can be a vast area of impact (measured in km²) for river restoration activities which may have been set as linear targets (km).

Source: Authors' own elaboration.

Table 3. Example restoration projects

Ecosystem function groups using IUCN Global Ecosystem Typology (Table 1)	Example Restoration Project	On-the-ground activities (Figure 2)	Enhancements expected	Area under restoration (method of area delineation)
F1.1 Permanent upland streams	**Headwater forest management**	Eliminating large areas of clear cut harvesting, increasing rotation times, protecting and restoring riparian zones (Reducing societal impacts)	Reduced hillslope erosion; support of natural food webs; protection of soil quality and natural flows; reduced transport of excess material (e.g. sediment, nutrients and water) to downstream systems	Subwatershed where on-the-ground activities occur (selected hydrobasin)
F1.1 Permanent upland streams	**Stream restoration**	Building pool habitat; removing bank stabilization measures; eliminating sediment mining (Initiating native recovery)	Increased habitat and bank complexity; increased natural sediment dynamics including sediment dispersal downstream; banks with more vegetation and shade leading to reduced stream temperatures	Subwatershed where on the ground activities occur; downstream watersheds until confluence with the larger downstream channel and the first set of subwatersheds along mainstem where sediments are now deposited to create more natural habitats; upstream watersheds where juvenile fish now migrate (selected hydrobasins)
F1.1 Permanent upland streams	**Culvert re-engineering or blockage removal**	Building more natural surface on culvert bottom (Improving ecosystem management)	Water velocity through the culvert is reduced and fishes are able to move through the culvert and access upstream areas; stream power downstream of the culvert during high flows is also reduced	Subwatershed where on the ground activities occur; upstream areas because native fishes are re-introduced with the enabled fish passage; river corridor downstream where natural patterns of sediment transportation are renewed. (Uploaded shape file including hydrobasins and hand-drawn polygon)

Ecosystem function groups using IUCN Global Ecosystem Typology (Table 1)	Example Restoration Project	On-the-ground activities (Figure 2)	Enhancements expected	Area under restoration (method of area delineation)
F1.1 Permanent upland streams	**Riparian restoration**	Tree planting and natural regeneration along both sides of the stream across an ecologically-functional buffer (Repairing ecosystem function)	Banks are stabilized with tree roots; leaves and terrestrial insects fall into the stream to support aquatic food webs; temperatures are reduced by shading; material transport into streams from upslope areas reduced	Stream corridor where on the ground activities occur; downstream stream corridor until confluence with the mainstem (hand-drawn polygon delineating stream corridor)
TF1.3 Permanent marshes **F3.2 Constructed lacustrine wetlands**	**Wetland restoration**	Replanting trees and natural regeneration, rewetting peatlands, construction of ecologically functional artificial wetlands (Repairing ecosystem function)	Improved soils and artificial wetlands support water storage and reduced flood risk during periods of high precipitation and support flow maintenance during periods of low precipitation; improved downstream water quality; increased native flora biodiversity and increased habitat for native fishes (juvenile life stage)	Subwatershed where on the ground activities occur; downstream subwatersheds until confluence with the mainstem (selected hydrobasins)

Ecosystem function groups using IUCN Global Ecosystem Typology (Table 1)	Example Restoration Project	On-the-ground activities (Figure 2)	Enhancements expected	Area under restoration (method of area delineation)
F2.1 Large permanent freshwater lakes	**Lake restoration**	Replanting trees across connected catchments; renaturalizing shorelines; restoration of small streams draining to the lake; re-planting submerged and emergent aquatic vegetation; re-introducing native fish species; removing non-native species; controlling pollution loads and sediments from catchment sources (Partially recovering native ecosystems)	Improved habitat for juvenile fishes and aquatic macroinvertebrates, waterfowl and aquatic vegetation; increased shade; reduced habitat erosion; reduced fine sediment inputs; reduced nutrient loading and harmful algal blooms; reduced pollutant loading and toxicity; reduced non-native invasive species; reduced hypoxia; improved hydrological connectivity	Subwatershed where on the ground activities occur; all connected subwatersheds above the lake where fish biodiversity is now expected to increase and/or non-native invasive species spread will be restricted (selected hydrobasins)
F1.7 Large lowland rivers	**Floodplain restoration**	Reconnecting side channels, levee setbacks, tree-planting, building pools, planting aquatic vegetation (Fully recovering native ecosystems)	Improved habitat for native fishes especially during critical periods of high and low water; reduced high flows downstream; increased sub-surface flows and increased connectivity with sub-surface flows; increased terrestrial inputs of insects and leaves to support local and downstream food webs; increased shade	Subwatershed where on the ground activities occur; all lateral subwatersheds; all subwatersheds downstream where enhanced biodiversity is expected; the next subwatershed upstream where enhanced biodiversity is expected (hand-drawn polygon and selected hydrobasins)

Notes: Example restoration projects as in Box 1B by relevant ecosystem functional group (Table 1) with a short description of on-the-ground activities that might be included (and where these activities might fall along the restorative continuum (Figure 2). Each type is connected to a simple summary of expected outcomes and example logic that explains the 'Area under restoration' that might be reported. These descriptions are all intended to be hypothetical examples. In a real watershed context, other on-the-ground activities might be included; other levels along the restorative continuum might be targeted; and the reported 'Area under restoration' would differ.

Source: Authors' own elaboration.

9.
MONITORING FRESHWATER (INLAND WATERS) RESTORATION

Thinking ahead to monitoring is important because the areas reported as 'areas under restoration' will naturally be those areas that are monitored in the future. Freshwater (inland waters) ecosystem restoration monitoring will be used to track the progress of on-the-ground activities (Nelson *et al.,* 2024). It can simultaneously serve as a tool for improving our understanding of restoration effectiveness and best practices as well as provide an early warning system for emerging threats to allow adaptive management. Monitoring will provide the framework for documenting the achievement of national targets and for information sharing (FAO, SCBD and SER; 2024).

Monitoring consists of both assessing whether restoration activities are taking place (implementation monitoring) and evaluating the impact of activities over time (effectiveness monitoring) (England *et al.,* 2021; Rogosch *et al.,* 2024). Implementation monitoring is relatively simple and generally consists of a survey describing information such as location, types of restoration activities, aims of the project, ecosystem type, partners, and even cost. It often also includes quantitative measures of project-related activities, e.g. the number of trees planted, the number of native fish reintroduced, or the number of culverts removed or made passable by fishes (Buckingham *et al.,* 2019).

Effectiveness monitoring can be divided into output monitoring, monitoring of the effects of the achieved activity (e.g. the number of hectares restored), and impact monitoring of the changes to ecosystem processes and landscape condition (e.g. changes in timing of flows, increases in fish populations, or improvements in water quality) (Buckingham *et al.* 2019). It is important to consider the difference because, generally, output monitoring is easier, requiring relatively simple, inexpensive, and stable indicators but it is problematic in that it can prioritize quantity over quality of restoration activity. Impact monitoring instead tracks the changes in ecological conditions of interest and helps future practitioners understand the degree to which particular activities are successful.

Impact monitoring is generally based on indicators of ecosystem condition and is particularly challenging in freshwater (inland waters) ecosystems because of:

1. the need to work at catchment scales;
2. strong seasonality in most relevant indicators such as water depth, water storage volume, water flow, water temperature, and biological communities (Lee *et al.,* 2023; Pekel *et al.,* 2016);
3. very high interannual variability, including hydroclimatic extremes such as droughts and floods;
4. expected long-time frames of impact (Gosling and Arnell, 2016; MacDonald, 2010; Vollmer *et al.* 2016).

Additionally, the scientific understanding of biogeochemical processes in some freshwater ecosystems needs strengthening (Jilbert *et al.,* 2020).

In general, the need for freshwater (inland waters) ecosystem monitoring at the country level represents a major issue for tracking progress on ecosystem restoration (Kissling *et al.,* 2018; Nesshöver *et al.,* 2016; Stephenson *et al.,* 2022; Stephenson *et al.,* 2017). Future guidance will need to build on existing monitoring systems and build on the experience of countries. According to "Guidance on needs related to implementing the monitoring framework of the Kunming-Montreal Global Biodiversity Framework" from the CBD Secretariat (CBD/SBSTTA/26/INF/14), there is an urgent need for support to Target 2. No CBD parties have responded that they will be able to report on Target 2 in the 7th national reports to CBD in February 2026 and 100 percent of parties responded that they need capacity development on methodologies for compiling the indicator in the national context, as well as support on data collection, and on institutional coordination for data reporting.

Experience from national dialogues organized by FAO and CIFOR/ICRAF around implementation of National Biodiversity Strategies and Action Plans (NBSAPs) indicate obstacles to adequate monitoring systems include:

- the high cost of monitoring system implementation;
- duplicative monitoring platforms;
- inadequate sharing of existing data;
- poor quality data or data in the wrong format;
- limited access to recent new technologies such; as high-resolution mapping;
- limited technical capacity on the ground.

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Many governments find it difficult to report accurately on their delivery of commitments under the CBD and other multilateral environmental agreements (Koh *et al.*, 2022; MacKenzie and Reardon, 2013) and the burden is particularly difficult for poorer countries. Looking at a related SDG indicator, only 3 percent of all data used to report on indicator 6.3.2 was provided by the poorer half of UN member states. The situation highlights again the challenges of monitoring and reporting water quality (UNEP, 2024).

These observations are in line with those described by others, for example, Mansourian and Stephenson 2023. Ideally then, monitoring needs to be both comprehensive and feasible.

Scientifically sound monitoring is, however, essential for ensuring the ecological effectiveness of the GBF. There can be a risk of restoration activities being implemented without adequate attention to ecologically relevant results. Recent evaluations of freshwater restoration for enhancing salmon populations in the Pacific Northwest of the United States of America show limited impact from billions spent on restoration (Bilby *et al.,* 2024; Jaeger and Scheurell, 2023). An example of good practice could be the recent Framework Act on Water Management (FAWM) enacted by the Government of the Republic of Korea, which aims to develop a national dual monitoring system of water quantity and quality, with monitoring water quantity and quality along river streams or at lakes and reservoirs, at consistent sampling times and frequencies (Lee *et al.,* 2023). The United States of America's Environmental Protection Agency also provides guidance on wetlands monitoring and assessment including establishing baselines, detecting change and characterizing trends over time (https://www.epa.gov/wetlands/wetlands-monitoring-and-assessment). And, for peatlands specific guidance is available from the tropics to the boreal zone (FAO, 2020).

10.
RELATIONSHIP BETWEEN REPORTING, MONITORING AND THREATS ASSESSMENT

Reporting for Target 2 of the GBF is the process of recording what restoration activities are underway and defining the area over which benefits are expected to accrue. It therefore also defines the area for monitoring. Effectiveness monitoring, and in particular impact monitoring, is one of the tools for assessing progress toward national commitments and effectiveness of international agreements but as described above, it is also a tool for observing the effects of climate change and assessing any risks or threats to ecosystems at the earliest opportunity.

Ideally then, reporting on 'Area under restoration', monitoring that area for restoration effectiveness, and assessing threats to watershed condition become an integrated system based on globally consistent data that are comparable over space and time.

Development of a set of indicators that can serve the purposes of reporting, monitoring and threats assessment will require standards in terms of baselines, scale, and terminology. Examples of key performance indicators could include total number of native aquatic species present, proportion of basin free-flowing, or forest cover change in riparian areas. It will, ideally, have a strong foundation in globally available data sets and be relatively inexpensive and simple to implement so that reporting is enabled for countries with few resources. Through careful planning, strong involvement of countries, and coordination across related reporting processes, such as SDG 6 and Target 3 of the GBF, duplication of effort can be avoided and a path can be provided for national reporting based on a strong ecological foundation and a clear data flow across platforms (e.g. Kuehne *et al.*, 2023).

11.
POTENTIAL INDICATORS AND DATA AVAILABILITY

The choice of monitoring indicators is crucial to ensure objective and robust monitoring of restoration targets and to provide valuable information on the health of freshwater ecosystems.

Local on-the-ground data are essential for evaluating specific restoration projects, particularly smaller projects. Reporting and monitoring can also be simplified and made more comparable through the use of remotely sensed data which can support tracking of changes in ecosystem condition and services over large areas. A large number of indicators and global data sets exist to complement and enhance tracking progress on Target 2 (Annex 1).

The work to be done is threefold. One element of the work is to select a suite of informative indicators that can efficiently capture key elements of freshwater condition sensitive to ecological degradation. The second element of the work is to refine the indicator so that it is relevant globally and across ecosystem types. The third element of the work is to enable consistent use and reporting.

A well-designed indicator is simple and based on ecosystem processes across watersheds. It should be efficient to collect, related to the driver of interest, sensitive to change but not so variable as to make change detection impossible. A well-designed indicator also incentivizes the right things so that unintended consequences are minimized (Biodiversity Indicators Partnership, 2011).

Indicators based on free global datasets and that build on the work already done or underway for tracking relevant SDG indicators, e.g. 6.6.1, are ideal. The SDG 6.6.1 portal's integration of hydrological and ecosystem specific data is a cost-effective tool for comprehensive monitoring of restoration progress. Geospatial data layers and Earth observation tools embedded in the portal are already adopted and used by UN Member States to track water quality, extent, and ecosystem health globally, and could be adapted for use under the Kunming-Montreal Framework. In this case, indicators should focus on tracking the desired outcomes of enhanced biodiversity, enhanced ecosystem functions and services, enhanced ecological integrity, and enhanced connectivity.

One key challenge highlighted by the SDG 6.6.1 portal is the lack of local data in many countries, which hinders consistent monitoring. Building capacity in-country for *in situ* monitoring is essential both to validate remotely sensed data and to provide an assessment of impacts for specific contexts. Capacity-building efforts can simultaneously focus on improving national monitoring systems and ensuring that countries can access and utilize tools like the Freshwater Ecosystem Explorer to track ecosystem and hydrological change. Another key challenge is the variability of freshwater conditions over time which can make it very difficult to detect changes even when they are occurring.

Related guidance exists for ecosystem service indicators (Brown *et al.,* 2014) and many related composite indicators for freshwater (inland waters) have been developed. For example, tools for assessment of river condition in a watershed context based on remotely sensed data have been proposed for prioritizing restoration (Glassic *et al.,* 2024; Riato *et al.,* 2023; Vollmer *et al.,* 2018). As well, there are innovative metrics for simplifying monitoring of temporally variable parameters in river systems such as water temperature (Steel *et al.,* 2017) and those suggested by Poff *et al.,* (1997) for restoring natural flow regimes. And general principles for evaluation such as relevance, coherence, effectiveness, efficiency, impact, and sustainability (OECD Evaluation Criteria).

We are not proposing specific monitoring indicators at this time but providing guiding principles, some example suggestions, and a synthesis of available data to support an in-depth dialogue and design of reporting tools, e.g. FERM, that can support integrated monitoring. (Annex 1: Available global data layers relevant for designing freshwater (inland waters) restoration monitoring indicators).

12.
CONCLUSIONS AND NEXT KEY CHALLENGES TO ADDRESS

Freshwater (inland waters) ecosystems are integral to a sustainable future. Restoring these critical ecosystems is fundamental to achieving the ambitions of the GBF. They differ from terrestrial and from marine and coastal ecosystems in important ways that need to be reflected in reporting and monitoring processes. There is a large body of expertise and well-developed ecological understanding to support this development.

Consistent reporting of 'Area under restoration', the headline indicator for Target 2 of the GBF, is a first step toward enabling and incentivizing this work. The definition proposed here is to include as 'Area under restoration' all areas over which any of the four desired outcomes of Target 2 are enhanced. These desired outcomes include biodiversity, ecosystem functions and services, ecological integrity, and ecological connectivity.

Reporting processes lay the foundation for ecologically relevant and effective long-term monitoring. Here we provide principles for reporting based on the interconnectedness of all elements within a watershed and the goals of Target 2. The 'Area under restoration' is the sum of the area of on-the-ground activities and those areas which are expected to have enhanced biodiversity, enhanced ecosystem functions and services, enhanced ecological integrity, and enhanced connectivity. Challenges remain in implementation and interpretation.

The remaining seven key challenges

1. **First,** the application of this guidance for reporting on "Area under restoration" in specific contexts and for particular restoration activities will require local expertise and an understanding of freshwater (inland waters) ecology. In particular, small scale restoration actions are challenging to quantify in this context. In the future, sharing of case studies will support the consistent global application of the general guidance laid out here and help to prevent ineffective restoration practices.

2. **The second challenge** is how best to link restoration prioritization, planning, reporting and monitoring across ecosystems. There is not a true boundary between terrestrial and aquatic systems. In many cases, restoration activities in terrestrial areas will have strong impacts (both positive and negative) on freshwater (inland waters) ecosystems. Restoration of marine and coastal areas is also likely to impact biodiversity in freshwater (inland waters) ecosystems. And restoring freshwater (inland waters) ecosystems is critical for the restoration of terrestrial and of marine and coastal ecosystems because wetlands are the essential regulator of the flow of water across landscapes (Convention on Wetlands, 2024a).

3. **Third,** although a large number of global and spatial datasets exist for monitoring freshwater (inland waters) restoration (Annex 1), the selection of an efficient set of indicators and data sets that are relevant globally is needed to ensure that restoration implementation leads to restoration effectiveness in enhancing ecological conditions. The carefull selection of indicators is essential to prevent unintended consequences such as enhanced connectivity leading to reduced biodiversity.

4. Fourth, there is a need for standards in terminology and assessment of baseline conditions. The availability of baseline information against which to monitor the effectiveness of restoration represents an important challenge (IPBES, 2018). The evolution of long-term ecosystem change needs to be measured against baseline conditions which are themselves variable and for which there may or may not be data (Pauly, 1995). To prepare for the future, climate change needs to be considered in the assessment of baselines.

5. Fifth, a particular challenge for freshwater (inland waters) restoration is the shortage of tools for prioritizing restoration activities. Often the tools that do exist are based on minimizing the cost of restoration while maximizing the return for that investment, literally 'biggest bang for your buck'. Some examples do exist such as Fonner *et al.,* (2022), Van Deynze *et al.,* (2022) and on-line tools, e.g. the National Aquatic Barrier Inventory and Prioritization Tool. Reflecting the growing need to quantify the financial costs of wetland loss and degradation, the forthcoming Global Wetland Outlook (GWO) 2025 is expected to provide critical insights into the financial costs of wetland loss, degradation, and the necessary scale of investment required for wetland restoration, while also offering recommendations on financing mechanisms, including nature-based solutions, to help meet global biodiversity and climate goals.

6. The sixth challenge is to provide more detailed guidance for when national boundaries and watershed boundaries do not align.

7. Seventh**,** the explicit incorporation of biological restoration as a component of ecological restoration needs to be enhanced. While restoration of habitat and restoration of inland fisheries stocks are tightly linked (e.g. Fitzpatrick *et al.,* 2021), it is possible to focus efforts on fish or other aquatic organisms without habitat modification. Examples might include re-introductions, removals of non-native predators, or fishing regulations. The same general principle will apply. The 'Area under restoration' is the area over which enhancements in any of the outcomes identified under Target 2 would be expected, in this case, particularly enhanced biodiversity. However, these examples need to be better incorporated into the language and thinking about restoration reporting and monitoring in order to enable effectively and consistently recording their benefits.

8. Finally, while this guidance is clear on the general principles to be applied and provides several generic examples of restoration activities and associated reporting areas (Box 1C, Table 3), further work is needed to guide identification of the upstream, downstream, and lateral boundaries at which, for example, biodiversity, connectivity, or ecological integrity enhancements remain measurable and reportable. Sharing of case studies can support consistent and reasonable reporting. Again context and local expertise will be needed with the goal of coherence across (a) ecosystems, (b) reporting platforms and mechanisms and (c) planning, implementation, and reporting of restoration activities.

References

Albert, J.S., Destouni, G., Duke-Sylvester, S.M., Magurran, A.E., Oberdorff, T., Reis, R.E., Winemiller, K.O. Ripple, W.J. 2020. *Scientists' warning to humassnity on the freshwater biodiversity crisis*. Ambio. 50:85-94.

Allan, J. D. 2004. Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems. *Annual Review of Ecology, Evolution, and Systematics*. 35, 257–284.https://doi.org/10.1146/annurev.ecolsys.35.120202.110122

Bilby, R. E., Currens, K. P., Fresh, K. L., Booth, D. B., Fuerstenberg, R. R., and Lucchetti, G. L. 2024. Why Aren't Salmon Responding to Habitat Restoration in the Pacific Northwest? *Fisheries* 49, 16–27. doi: https://doi.org/10.1002/fsh.10991

Biodiversity Indicators Partnership. 2011. *Guidance for national biodiversity indicator development and use.* UNEP World Conservation Monitoring Centre, Cambridge, UK. Available at https://www.bipindicators.net/system/resources/files/000/002/191/original/Framework_Brochure_UK_0311_LOWRES_%281%29.pdf

Brauman, K.A., Daily, G.C., Duarte, T.K., Mooney, H.A. 2007. The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. *Annual Review of Environment and Resources*. 32, 67–98. https://doi.org/10.1146/annurev.energy.32.031306.102758

Broadley, A., Stewart-Koster, B., Burford, M. A., and Brown, C. J. 2022. A global review of the critical link between river flows and productivity in marine fisheries. *Reviews in Fish Biology* and Fisheries, 32: 805-825. doi: 10.1007/s11160-022-09711-0

Brown, C., Reyers, B., Ingwall-King, L., Mapendembe, A., Nel, J., O'Farrell, P., Dixon, M. Bowles-Newark, N. J. 2014. Measuring ecosystem services: Guidance on developing ecosystem service indicators. UNEP-WCMC, Cambridge, UK.

Brownlie, W.J., M.A. Sutton, K.V. Heal, D.S. Reay, B.M. Spears. (eds.) 2022. *Our Phosphorus Future*. UK Centre for Ecology and Hydrology, Edinburgh. doi: 10.13140/RG.2.2.17834.08645

Buckingham, K., Ray, S., Gallo-Granizo, C., Toth, L., Zoveda, F., Reytar, K., Zamora-Cristales, R., Ndunda, P., Landsberg, F., Matsumoto, M., Brandt, J. 2019. *The Road to Restoration A Guide to Identifying Priorities and Indicators for Monitoring Forest and Landscape Restoration*.

Challis, J.K., Popick, H., Prajapati, S., Harder, P., Giesy, J.P., McPhedran, K. and Brinkmann, M. 2021. Occurrences of tire rubber-derived contaminants in cold-climate urban runoff. *Environmental Science Technology Letters*, *8*(11), pp.961-967.

Convention on Wetlands,2024a. *Scaling up wetland conservation and restoration to deliver the Kunming-Montreal Global Biodiversity Framework: Guidance on including wetlands in National Biodiversity Strategy and Action Plans (NBSAPs) to boost biodiversity and halt wetland loss and degradation. Ramsar Technical Report No. 12*. Gland, Switzerland: Secretariat of the Convention on Wetlands. DOI: 10.69556/strp.tr12.24

Convention on Wetlands. 2024b. *Submission from the Convention on Wetlands to the 6th meeting of the Ad Hoc Technical Expert Group on Indicators on the effective consideration of wetlands in the KMGBF Monitoring Framework*. SC63 Inf.3. Available at https://www.ramsar.org/sites/default/files/2024-03/SC63_Inf_3_ahteg_submission_e.pdf

Costanza, R., De Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S. and Turner, R.K. 2014. *Changes in the global value of ecosystem services. Global environmental change* .

Davidson, N.C. 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. Marine and Freshwater Research. 65, 934. https://doi.org/10.1071/MF14173

Department of Environment and Science. 2023. *Queensland Wetland Classification Scheme Version 2.0*, Queensland Government, Brisbane. Available at https://wetlandinfo.des.qld.gov.au/resources/static/pdf/facts-maps/mapping/queensland-wetland-classification-scheme.pdf

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L. Sullivan, C.A. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews*, 81(2): 163–182.

EEA. 2018. *European waters. Assessment of status and pressures 2018* (No. Report No 7/2018).

England, J., Angelopoulos, N., Cooksley, S., Dodd, J., Gill, A., Gilvear, D., Johnson, M., Naura, M., O'Hare, M., Tree, A., Wheeldon, J. Wilkes, M.A. 2021. Best practices for monitoring and assessing the ecological response to river restoration. *Water*, 13.

European Commission. Joint Research Centre. 2020. *Mapping and assessment of ecosystems and their services: an EU wide ecosystem assessment in support of the EU biodiversity strategy.* Publications Office, LU.

FAO. 2014. *Towards climate-responsible peatlands* *management.* Rome, Italy. https://openknowledge.fao.org/items/c39aaa98-110e-4884-bca0-8dde5a38726d

FAO. 2020. *Peatland mapping and monitoring. Recommendations and technical overview*. Rome, Italy. https://openknowledge.fao.org/server/api/core/bitstreams/1d5817ad-1385-4cfb-85ca-072ae9778eff/content

FAO, SCBD SER. 2024. *Delivering restoration outcomes for biodiversity and human well-being – Resource guide to Target 2 of the Kunming-Montreal Global Biodiversity Framework.* Rome, Montreal, Canada, and Washington, DC. https://doi.org/10.4060/cd2925en

Fitzpatrick, K.B., Moddy, A.T., Milt, A., Herbert, M.E., Khoury, M., Yacobson, E., Ross, J.A., Doran, P.J., Ferris, M.C., McIntyre, P.B. Neeson, T.M. 2021. Can indicator species guide conservation investments to restore connectivity in Great Lakes tributaries? *Biodiversity and Conservation*, 30: 165–182. https://doi.org/10.1007/s10531-020-02084-5

Fluet-Chouinard, E., Stocker, B.D., Zhang, Z., *et al*. 2023. Extensive global wetland loss over the past three centuries. *Nature*, 614: 281–286. https://doi.org/10.1038/s41586-022-05572-6

Fonner, R., Izón, G., Feist, B.E. Barnas, K. 2022. Capitalization of reduced flood risk into housing values following a floodplain restoration investment. *Journal of Environmental Economics and Policy*, 12: 305–323. https://doi.org/10.1080/21606544.2022.2136765

Garcia-Moreno, J., Harrison, I.J., Dudgeon, D., Clausnitzer, V., Darwall, W., Farrell, T., Savy, C., Tockner, K. Tubbs, N. 2014. Sustaining freshwater biodiversity in the Anthropocene. In Pahl-Wostl, C., *et al*., eds. *The global water system in the Anthropocene*, pp. 247–270. Springer, New York, NY, USA.

Glassic, H.C., McGwire, K.C., Macfarlane, W.W., Rasmussen, C., Bouwes, N., Wheaton, J.M. 2024. From pixels to riverscapes: How remote sensing and geospatial tools can prioritize riverscape restoration at multiple scales. *WIREs Water*, 11: e1716. https://doi.org/10.1002/wat2.1716

Gleick, P.H. (Ed.). 2014. *The world's water.* Island Press/Center for Resource Economics, Washington, DC. https://doi.org/10.5822/978-1-61091-483-3

Gosling, S.N. Arnell, N.W. 2016. A global assessment of the impact of climate change on water scarcity. *Climatic Change*, 134: 371–385. https://doi.org/10.1007/s10584-013-0853-x

Hallouin, T., Bruen, M., Christie, M., Bullock, C. Kelly-Quinn, M. 2018. Challenges in using hydrology and water quality models for assessing freshwater ecosystem services: A review. *Geosciences*, 8: 45. https://doi.org/10.3390/geosciences8020045

IPBES. 2018. *The IPBES assessment report on land degradation and restoration.* Zenodo. https://doi.org/10.5281/ZENODO.3237392

Jaeger, W.K. Scheuerell, M.D. 2023. Return(s) on investment: Restoration spending in the Columbia River Basin and increased abundance of salmon and steelhead. *PLOS ONE*, 18: e0289246. https://doi.org/10.1371/journal.pone.0289246

Jansson, R., Nilsson, C. Malmqvist, B. 2007. Restoring freshwater ecosystems in riverine landscapes: The roles of connectivity and recovery processes. *Freshwater Biology*, 52: 589–596. https://doi.org/10.1111/j.1365-2427.2007.01737.x

Jilbert, T., Couture, R.-M., Huser, B.J. Salonen, K. 2020. Preface: Restoration of eutrophic lakes: Current practices and future challenges. *Hydrobiologia*, 847: 4343–4357. https://doi.org/10.1007/s10750-020-04457-x

Karr, J.R. 1991. Biological integrity: A long-neglected aspect of water resource management. *Ecological Applications*, 1(1): 66–84.

Karr, J.R. 1999. Defining and measuring river health. *Freshwater Biology*, 41(2): 221–234.

Keith, D.A., Ferrer-Paris, J.R., Nicholson, E. Kingsford, R.T., eds. 2020. *The IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups.* Gland, Switzerland: IUCN.

Kissling, W.D., Ahumada, J.A., Bowser, A., Fernandez, M., Fernández, N., García, E.A., Guralnick, R.P., Isaac, N.J.B., Kelling, S., Los, W., McRae, L., Mihoub, J., Obst, M., Santamaria, M., Skidmore, A.K., Williams, K.J., Agosti, D., Amariles, D., Arvanitidis, C., Bastin, L., De Leo, F., Egloff, W., Elith, J., Hobern, D., Martin, D., Pereira, H.M., Pesole, G., Peterseil, J., Saarenmaa, H., Schigel, D., Schmeller, D.S., Segata, N., Turak, E., Uhlir, P.F., Wee, B. Hardisty, A.R. 2018. Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale. *Biological Reviews*, 93: 600–625. https://doi.org/10.1111/brv.12359

Koh, N.S., Ituarte-Lima, C. Hahn, T. 2022. Mind the compliance gap: How insights from international human rights mechanisms can help to implement the Convention on Biological Diversity. *Transnational Environmental Law*, 11: 39–67. https://doi.org/10.1017/S2047102521000169

Kuehne, L.M., Dickens, C., Tickner, D., Messager, M.L., Olden, J.D., *et al*. 2023. The future of global river health monitoring. *PLOS Water*, 2(9): e0000101. https://doi.org/10.1371/journal.pwat.0000101

Kummu, M., De Moel, H., Ward, P.J. Varis, O.

2011. How close do we live to water? A global analysis of population distance to freshwater bodies. *PLOS ONE*, 6(6): e20578.

Kupilas, B., *et al*. 2024. *Compilation of existing guidance on ecosystem restoration.* Ecologic Institute, Berlin. Available at https://www.ecologic.eu/sites/default/files/publication/2024/50134-Compilation-of-restoration-guidance_0.pdf

Lee, K.H., Ali, S., Kim, Y., Lee, K., Kwon, S.Y. Kam, J. 2023. High-resolution mapping of nitrate loads of a reservoir using an uncrewed surface vehicle: Potential opportunities and challenges. *Water Resources Research*, 59: e2023WR034665. https://doi.org/10.1029/2023WR034665

Lynch A.J., Elliott, V., Phang, S.C., Claussen, J.E., Harrison, I., KJ Murchie, Steel E.A. Stokes, G.L. 2020. Inland fish and fisheries integral to achieving the Sustainable Development Goals. *Nature Sustainability* 4:1-9.

MacDonald, G.M. 2010. Water, climate change, and sustainability in the southwest. *Proceedings of the National Academy of Sciences*, 107: 21256–21262. https://doi.org/10.1073/pnas.0909651107

MacKenzie, D.I. Reardon, J.T. 2013. Occupancy methods for conservation management. In Collen, B., Pettorelli, N., Baillie, J.E.M. Durant, S.M., eds. *Biodiversity monitoring and conservation*, pp. 248–264. Wiley. https://doi.org/10.1002/9781118490747.ch11

Mansourian, S. Stephenson, P.J. 2023. Exploring challenges and lessons for monitoring forest landscape restoration. *Current Landscape Ecology Reports*, 8: 159–170. https://doi.org/10.1007/s40823-023-00092-z

Nahlik, A. Fennessy, M. 2016. Carbon storage in US wetlands. *Nature Communications*, 7: 13835. https://doi.org/10.1038/ncomms13835

Naylor, R.L., Hardy, R.W., Buschmann, A.H., *et al*. 2021. A 20-year retrospective review of global aquaculture. *Nature*, 591: 551–563. https://doi.org/10.1038/s41586-021-03308-6

Nelson, C.R., Hallett, J.G., Romero Montoya, A.E., Andrade, A., Besacier, C., Boerger, V., Bouazza, K., Chazdon, R., Cohen-Shacham, E., Danano, D., Diederichsen, A., Fernandez, Y., Gann, G.D., Gonzales, E.K., Gruca, M., Guariguata, M.R., Gutierrez, V., Hancock, B., Innecken, P., Katz, S.M., McCormick, R., Moraes, L.F.D., Murcia, C., Nagabhatla, N., Pouaty Nzembialela, D., Rosado-May, F.J., Shaw, K., Swiderska, K., Vasseur, L., Venkataraman, R., Walder, B., Wang, Z. Weidlich, E.W.A. 2024. Standards of practice to guide ecosystem restoration – A contribution to the United Nations Decade on Ecosystem Restoration 2021–2030. Rome, FAO, Washington, DC, SER Gland, Switzerland, IUCN CEM. https://doi.org/10.4060/cc9106en

Nesshöver, C., Livoreil, B., Schindler, S. Vandewalle, M. 2016. Challenges and solutions for networking knowledge holders and better informing decision-making on biodiversity and ecosystem services. *Biodiversity and Conservation*, 25: 1207–1214. https://doi.org/10.1007/s10531-016-1124-8

Palmer, M.A., Ambrose, R.F. Poff, N.L.R. 1997. Ecological theory and community restoration ecology. *Restoration Ecology*, 5: 429–439.

Pauly, D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology Evolution*, 10: 430. https://doi.org/10.1016/S0169-5347(00)89171-5

Pekel, J.-F., Cottam, A., Gorelick, N. Belward, A.S. 2016. High-resolution mapping of global surface water and its long-term changes. *Nature*, 540: 418–422. https://doi.org/10.1038/nature20584

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. Stromberg, J.C. 1997. The natural flow regime. *BioScience*, 47: 769–784.

Poikane, S., Kelly, M.G., Free, G., Carvalho, L., Hamilton, D.P., Katsanou, K., Lürling, M., Warner, S., Spears, B.M., Irvine, K. 2024. A global assessment of lake restoration in practice: New insights and future perspectives. *Ecological Indicators*, 158: 111330. https://doi.org/10.1016/j.ecolind.2023.111330

Postel, S.L. Thompson, B.H. 2005. Watershed protection: Capturing the benefits of nature's water supply services. *Natural Resources Forum*, 29: 98–108. https://doi.org/10.1111/j.1477-8947.2005.00119.x

Reynaud, A. Lanzanova, D. 2017. A global meta-analysis of the value of ecosystem services provided by lakes. *Ecological Economics*, 137: 184–194. https://doi.org/10.1016/j.ecolecon.2017.03.001

Riato, L., Leibowitz, S.G., Weber, M.H. Hill, R.A. 2023. A multiscale landscape approach for prioritizing river and stream protection and restoration actions. *Ecosphere*, 14: e4350. https://doi.org/10.1002/ecs2.4350

Ricaurte, L.F., Patiño, J.E., Zambrano, D.F.R., *et al*. 2019. A classification system for Colombian wetlands: An essential step forward in open environmental policy-making. *Wetlands*, 39: 971–990. https://doi.org/10.1007/s13157-019-01149-8

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T., Kidd, K.A., MacCormack, T.J. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, 94: 849–873.

Rogosch, J.S., Boehm, H.I.A., Tingley III, R.W., Wright, K.D., Webb, E.B. Paukert, C.P. 2024. Evaluating effectiveness of restoration to address current stressors to riverine fish. *Freshwater Biology*, 69: 607–622.

Shiklomanov, I.A. Rodda, J.C., eds. 2003. *World water resources at the beginning of the twenty-first century.* International hydrology series. Cambridge, UK ; New York, USA, Cambridge University Press.

Spears, B.M., Sutton, M.A., Heal, K.V., Reay, D.S. Brownlie, W.J. 2022. Chapter 1: Our phosphorus future – An introduction. In Brownlie, W.J., Sutton, M.A., Heal, K.V., Reay, D.S. Spears, B.M., eds. *Our phosphorus future.* UK Centre for Ecology Hydrology, Edinburgh. https://doi.org/10.13140/RG.2.2.32933.58085

Steel, E.A., Marsha, A., Fullerton, A.H., Olden, J.D., Larkin, N.K., Lee, S.Y. Ferguson, A. 2019. Thermal landscapes in a changing climate: Biological implications of water temperature patterns in an extreme year. *Canadian Journal of Fisheries and Aquatic Sciences*, 76: 1740–1756. https://doi.org/10.1093/biosci/bix047

Stephenson, P.J., Bowles-Newark, N., Regan, E., Stanwell-Smith, D., Diagana, M., Höft, R., Abarchi, H., Abrahamse, T., Akello, C., Allison, H., Banki, O., Batieno, B., Dieme, S., Domingos, A., Galt, R., Githaiga, C.W., Guindo, A.B., Hafashimana, D.L.N., Hirsch, T., Hobern, D., Kaaya, J., Kaggwa, R., Kalemba, M.M., Linjouom, I., Manaka, B., Mbwambo, Z., Musasa, M., Okoree, E., Rwetsiba, A., Siam, A.B. Thiombiano, A. 2017. Unblocking the flow of biodiversity data for decision-making in Africa. *Biological Conservation*, 213: 335–340. https://doi.org/10.1016/j.biocon.2016.09.003

Stephenson, P.J., Londoño-Murcia, M.C., Borges, P.A.V., Claassens, L., Frisch-Nwakanma, H., Ling, N., McMullan-Fisher, S., Meeuwig, J.J., Unter, K.M.M., Walls, J.L., Burfield, I.J., Do Carmo Vieira Correa, D., Geller, G.N., Montenegro Paredes, I., Mubalama, L.K., Ntiamoa-Baidu, Y., Roesler, I., Rovero, F., Sharma, Y.P., Wiwardhana, N.W., Yang, J. Fumagalli, L. 2022. Measuring the impact of conservation: The growing importance of monitoring fauna, flora, and funga. *Diversity*, 14: 824. https://doi.org/10.3390/d14100824

Stoakes, G.L., Lynch, A.J., Smidt, S.J., Steel, E.A., Dowd, S., Britton, J.R., Bai, X., Cerquera, T.B., Guerrero, G., Cheramy, J., Koning, A., Maghsood, F.F., Piccillo, A. Schuppie, G. 2024. Life on land needs fresh water (SDG 15). In Water Matters: Achieving the Sustainable Development Goals, Mukherjee, A. (ed.), (pp. 295-309). Elsevier.

Talbot, R. Chang, H. 2022. Microplastics in freshwater: A global review of factors affecting spatial and temporal variations. *Environmental Pollution*, 292: 118393.

UNEP. 2024. *GEMStat: New report on UN SDG indicator 6.3.2 released* **[accessed on 27 January 2025]** https://gemstat.org/2024-sdg-632/

Van Deynze, B., Fonner, R., Feist, B.E., Jardine, S.L. Holland, D.S. 2022. What influences spatial variability in restoration costs? Econometric cost models for inference and prediction in restoration planning. *Biological Conservation*, 274: 109710. https://doi.org/10.1016/j.biocon.2022.109710

Vannote, R.L. 1981. The river continuum: A theoretical construct for analysis of river ecosystems. *Proceedings of the National Symposium on Freshwater Inflow to Estuaries*, 2: 289–304.

Vollmer, D., Regan, H.M. Andelman, S.J. 2016. Assessing the sustainability of freshwater systems: A critical review of composite indicators. *Ambio*, 45: 765–780. https://doi.org/10.1007/s13280-016-0792-7

Vollmer, D., Shaad, K., Souter, N.J., Farrell, T., Dudgeon, D., Sullivan, C.A. 2018. Integrating the social, hydrological, and ecological dimensions of freshwater health: The Freshwater Health Index. *Science of the Total Environment*, 627C: 304–313.

Wheaton, J.M., Bennett, S.N., Bouwes, N., Camp, R., Maestas, J.D. Shahverdian, S.M. 2019. Chapter 2: Principles of low-tech process-based restoration. In Wheaton, J.M., Bennett, S.N., Bouwes, N., Maestas, J.D. Shahverdian, S.M., eds. *Low-tech process-based restoration of riverscapes: Design manual.* Logan, Utah, Utah State University Restoration Consortium. 30 pp.

Wilson, M.A. Carpenter, S.R. 1999. Economic valuation of freshwater ecosystem services in the United States: 1971–1997. *Ecological Applications*, 9: 772. https://doi.org/10.2307/2641328

Wohl, E., Lane, S.N. Wilcox, A.C. 2015. The science and practice of river restoration. *Water Resources Research*, 51: 5974–5997.

WWF. 2020. *Living Planet Report 2020 – Bending the curve of biodiversity loss: A deep dive into freshwater.* Almond, R.E.A., Grooten, M. Petersen, T., eds. Gland, Switzerland, WWF.

WWQA Ecosystems. 2023. *White paper – Embedding lakes into the global sustainability agenda.* UK Centre for Ecology Hydrology on behalf of UNEP-coordinated World Water Quality Alliance Ecosystems Workstream. ISBN: 978-1-906698-82-9. https://doi.org/10.5281/zenodo.7752982

Annex 1. Potential indicators using global datasets

Introduction

Recent global advancements in Earth observation and remote sensing technologies have substantially improved the quantity and quality of data available for monitoring the past, current, and future status and dynamics of global freshwater (inland waters) ecosystems. For example, advances in temporal resolution allow for data collection to occur over days or weeks rather than years or decades. Similarly, advances in spatial resolution (e.g. 30m or even 10m) improve the identification of characteristics and the resolution at which current conditions and restoration can be tracked.

Advantages in the use of remote sensing data for freshwater (inland waters) monitoring include:

1. the ability to collect data over expansive, heterogeneous and often inaccessible areas;
2. the ability to detect fine-scale changes that would otherwise require vast resources to accomplish, such as water quality measurements;
3. global coherence in data and information underlying monitoring;
4. real-time monitoring and rapid assessments to inform timely management responses (e.g. extreme weather events).

By providing timely and accurate data, remote sensing technologies empower policymakers, researchers, and managers to make informed decisions for freshwater (inland waters) management and restoration efforts.

Utility of spatial data for freshwater (inland waters) monitoring

Earth observation data offers several key applications for monitoring freshwater (inland waters) ecosystems, including the following purposes with examples of broad relevant databases for each (see Table 1 for specific attributes):

1 Baseline assessment

Regularly collected remotely sensed data provide baseline identification of water bodies, vegetation, and surrounding land use, enabling comparisons before and after restoration.

- Global Lakes and Wetlands Database (GLWD): Contains information on lakes and wetlands extent that can be connected with water quality assessments.
- HydroSHEDS: Offers spatial data on river networks and watershed areas, which can be used to relate land use and water quality data.
- EarthData (NASA): Provides access to a wide range of data relevant to freshwater (inland waters), such as soil moisture and surface water dynamics.
- NASA's MODIS (Moderate Resolution Imaging Spectroradiometer): Provides satellite imagery that can be used to monitor various aquatic parameters, including water temperature, chlorophyll concentration, and surface water extent.

2 Change detection

Multitemporal satellite imagery allows for the detection of changes over time and to evaluate restoration effectiveness and identify priority areas.

- Global Surface Water Explorer: Provides information on the presence and extent of surface water bodies globally to track changes over time.
- GLIMS (Global Land Ice Measurements from Space): Provides a global inventory of glaciers and ice caps, including data on glacier outlines and changes in area and volume.
- GRanD (Global Reservoir and Dam Database): Contains information on reservoirs, which can be analyzed to assess the impact of climate variability on water storage and availability.
- Aqueduct Global Maps: Developed by the World Resources Institute, assesses water risk, including the impacts of climate change on freshwater resources and availability.

3 Water quality monitoring

Earth observation tools can detect water quality indicators, such as chlorophyll levels and sediment concentrations, and inform restoration impacts on water quality.

- World Bank Water Quality Database: Provides data on water quality indicators, including microbiological and chemical contaminants from global monitoring programs.
- Copernicus Sentinel-2: Offers high-resolution optical imagery for assessing water quality indicators like suspended solids, chlorophyll-a, and other contaminants.

4 Water quantity (e.g. hydrology and flow patterns) monitoring

Remote sensing helps monitor changes in hydrological patterns, such as surface water extent and flow dynamics, which are crucial for understanding the effects of restoration.

- GLOFAS (Global Flood Awareness System): Provides real-time and historical flood data, including river discharge and flood risk assessments.
- Global River Discharge Database: Contains discharge data for major rivers worldwide, essential for understanding river flow patterns and hydrological modeling.
- World Bank Water Data: A collection of data related to freshwater resources, water use, and management, contributing to global water policy and research.
- Global Hydrology Resource Center (GHRC): Offers various datasets related to hydrology, including precipitation, evaporation, and river flow data.

5 Land use and land cover analysis

Monitoring changes in land use around freshwater systems, including riparian zones and wetlands, can inform human impact mitigation and strategies for restoration projects in riparian zones and wetlands.

- Global Land Cover (GLC) Datasets: Includes various datasets, such as the European Space Agency's Climate Change Initiative Land Cover and the GLC2000, which provide global land cover classifications.
- World Resources Institute (WRI) Global Forest Change: Offers datasets on global forest cover change, deforestation, and forest gain using Landsat imagery.

Catchment scale monitoring

The highly transboundary nature of global freshwater (inland waters) ecosystems necessitates the use of a catchment or basin (watershed) level approach when considering attributes and potential indicators. This presents a challenge with traditional, country-level datasets; however remote sensing data with global coverage overcomes this potential obstacle and allows for a more accurate estimate of the area under restoration. The need to work at catchment scales is an imperative for reporting freshwater (inland waters) condition. The global hydrological delineation framework (HydroSHEDS; included in FERM) enables the summarization of data into 10 nested sizes of watersheds (levels 3 to 12) and integration with river (HydroRIVERS) and lake attributes (HydroLAKES).

Potential indicators and datasets

The Convention on Wetlands' Scientific and Technical Review Panel (STRP) highlights two component indicators that could help address the gap in understanding restoration outcomes for inland contexts:

1. Extent of natural ecosystems by type (ID 323); and
2. Maintenance and restoration of connectivity of natural ecosystems (ID 324) (Convention on Wetlands, 2024b) (SC63 Inf.3).

The extent of natural ecosystems by type (ID 323) for inland waters may be measured using the Freshwater Ecosystem Explorer platform (e.g. wetland quantity, quality and flow data) and the Global Mangrove Watch data (already listed as a complementary indicator ID 950). Maintenance and restoration of connectivity of natural ecosystems (ID 324) in the context of inland waters may be measured using the Free flowing rivers indicator (ID 1060; River connectivity status index). In addition, the Freshwater health index could provide composite information on basin health. The FAO assessment of global water stress on freshwater environments (SDG 6.4.2) may be useful for water use rankings, and Global Wetland Watch (coming in 2025) will capture real-time data on wetland quantity and extent (not quality) to support restoration outcomes for wetlands.

While a large number of spatial datasets exist for monitoring freshwater (inland waters) restoration, selecting a relevant set with global coverage, regular updates, and open-source availability is key for ensuring monitoring system that allows for tracking effectiveness. Here, we provide a suite of available resources to aid in the monitoring of freshwater ecosystem restoration. The Kunming-Montreal Global Biodiversity Framework (GBF) Target 2 desired outcome categories (Column 1) include:

1. enhanced biodiversity
2. enhanced ecosystem functions and services
3. enhanced ecological integrity
4. enhanced connectivity.

The primary ecological attributes (Column 2) are derived from the five key ecological attributes in freshwater systems:

1. hydrologic regime (timing, duration, magnitude, frequency)
2. connectivity (longitudinal, lateral, vertical, temporal)
3. water quality
4. habitat complexity
5. biotic composition (Karr 1991; Karr 1999).

Relevant biomes (Column 5) are derived from the inland freshwater biomes considered in the IUCN Global Ecosystem Typology (Keith *et al.,* 2020) (Table 1):

F1 rivers and streams

F2 lakes

F3 artificial wetlands

TF1 palustrine wetlands

SF1 subterranean freshwaters

SF2 anthropogenic subterranean freshwaters

These data layers can eventually also be combined with other types of spatially explicit information to add nuance. For example, they could be combined with human population density for estimating progress in "delivering benefits essential for all people."

Table A1. Potential datasets for use as indicators of freshwater restoration and monitoring

Primary GBF Target 2 desired outcome category	Primary ecological attribute	Attribute / potential indicator	Source dataset(s)	Relevant biomes
Enhanced ecological integrity	Habitat complexity	Protected areas in watersheds	Source data: Protected Areas of the World Reference: Bingham *et al.*, 2019	*ALL*
Enhanced connectivity	Connectivity	Free-flowing rivers	Source data: Mapping the world's free-flowing rivers Reference: Grill *et al.*, 2019	F1 Rivers and streams biome
Enhanced ecological integrity	Habitat complexity	Vegetated riparian areas (proportion of riparian area with vegetation to built or bare area)	Source data: Copernicus Global Land Service: Land Cover 100m Reference: Buchhorn *et al.,* 2020	*ALL*
Enhanced ecosystem functions and services	Habitat complexity	Forest cover change in basin or riparian areas	Source data: Global Forest Change 2000-2021 Reference: Hansen *et al.*, 2013	*ALL*
Enhanced ecosystem functions and services	Water quality	Lake water quality (including trophic level index, chlorophyll a, and/ turbidity)	Source data: Lake Water Quality 2019-present Reference: Stelzer *et al.*, 2024	F2 Lakes biome
Enhanced biodiversity	Biotic composition	Watershed level invasive species	Source data: Number of Harmful Invasive Species by Freshwater Ecoregion Reference: TNC 2009	*ALL*
Enhanced ecological integrity	Habitat complexity	Wetland gain / loss	Source data: Global wetland loss reconstruction over 1700-2020 Reference: Fluet-Chouinard *et al.*, 2023	TF1 Palustrine wetlands biome
Enhanced ecosystem functions and services	Hydrologic regime	Water stress and variability (including water consumption, withdrawals, discharge, depletion, demand, drought, and risks)	Source data: Aqueduct Water Risk Atlas 4.0 Reference: Kuzma *et al.*, 2023 Source data: Palmer Drought Severity Index Reference: Dai 2021	*ALL*
Enhanced ecosystem functions and services	Hydrologic regime	Water use (present and future)	Source Data: Global monthly sectoral water use for 2010-2100 Reference: Khan *et al.*, 2023	*ALL*
Enhanced ecosystem functions and services	Water quality	River sediment composition and flux	Source data: Global River Sediments (GloRiSe) Reference: Müller *et al.*, 2021 Source data: Global river suspended sediment concentrations Reference: Dethier *et al.*, 2022	F1 Rivers and streams biome

Enhanced biodiversity	Biotic composition	Climate impacts on fish species	Source data: Fish species impacted by future flow and water temperature extremes Reference: Barbarossa *et al.*, 2021	F1 Rivers and streams biome
Enhanced ecosystem functions and services	Habitat complexity	Phenological shifts (duration, timing) in lake stratification	Source data: Global annual lake ice phenological dataset 1861-2099 (GLIP) Reference: Wang Feng 2022 Source data: ESA Lakes climate change initiative Reference: Woolway *et al.*, 2021	F2 Lakes biome
Enhanced ecological integrity	Hydrologic regime	Lake depth, volume, shoreline (baseline data)	Source data: HydroLAKES Reference: Messenger *et al.*, 2016	F2 Lakes biome
Enhanced ecosystem functions and services	Hydrologic regime	River discharge, width, length, classification (baseline data)	Source data: HydroRIVERS Reference: Lehner Grill, 2013	F1 Rivers and streams biome
Enhanced ecosystem functions and services	Hydrologic regime	Future streamflow and water temperature	Source data: FutureStreams Reference: Bosmans et al., 2022	F1 Rivers and streams biome
Enhanced ecosystem functions and services	Water quality	Nutrient inputs, loads, and dynamics (including nitrogen, phosphorus, and other grey water sources)	Source data: PEST-CHEMGRIDS Reference: Maggi et al., 2019 Source data: EarthSTAT Nutrient Application for Major Crops Reference: Mueller *et al.*, 2012; West *et al.*, 2014 Source data: Global grey water footprint Reference: Mekonnen Hoeskstra, 2015	*ALL*
Enhanced ecological integrity	Habitat complexity	Riverbank erosion	Source data: Riverbank Erosion and Accretion from Landsat (REAL) Reference: Langhorst Pavlensky, 2023	F1 Rivers and streams biome

Sources:

Barbarossa, V., Bosmans, J., Wanders, N., King, H., Bierkens, M. F., Huijbregts, M. A., Schipper, A. M. *(2021). Threats of global warming to the world's freshwater fishes. Nature communications, 12(1), 1701.* https://doi.org/10.1038/s41467-021-21655-w

Bingham, H. C., Juffe Bignoli, D., Lewis, E., MacSharry, B., Burgess, N. D., Visconti, P., ... Kingston, N. *(2019). Sixty years of tracking conservation progress using the World Database on Protected Areas. Nature ecology evolution, 3(5), 737-743.* https://doi.org/10.1038/s41559-019-0869-3

Bosmans, J., Wanders, N., Bierkens, M. F., Huijbregts, M. A., Schipper, A. M., Barbarossa, V. *(2022). FutureStreams, a global dataset of future streamflow and water temperature. Scientific data, 9(1), 307.* https://doi.org/10.1038/s41597-022-01410-6

Buchhorn, M., Smets, B., Bertels, L., De Roo, B., Lesiv, M., Tsendbazar, N. E., ... Fritz, S. *(2020). Copernicus global land service: land cover 100m: collection 3 Epoch 2015, Globe. Version V3. 0.1) [Data set].* https://doi.org/10.5281/zenodo.3939038

Dai, A. *(2021). Hydroclimatic trends during 1950–2018 over global land. Climate Dynamics, 56(11), 4027-4049.* https://doi.org/10.1007/s00382-021-05684-1

Dethier, E. N., Renshaw, C. E., Magilligan, F. J. *(2022). Rapid changes to global river suspended sediment flux by humans. Science, 376(6600), 1447-1452.* https://doi.org/10.1126/science.abn7980

Fluet-Chouinard, E., Stocker, B. D., Zhang, Z., Malhotra, A., Melton, J. R., Poulter, B., ... McIntyre, P. B. *(2023). Extensive global wetland loss over the past three centuries. Nature, 614(7947), 281-286.* https://doi.org/10.1038/s41586-022-05572-6

Grill, G., Lehner, B., Thieme, M., Geenen, B., Tickner, D., Antonelli, F., ... Zarfl, C. *(2019). Mapping the world's free-flowing rivers. Nature, 569(7755), 215-221.* https://doi.org/10.1038/s41586-019-1111-9

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., ... Townshend, J. *R. (2013). High-resolution global maps of 21st-century forest cover change. science, 342(6160), 850-853.* https://doi.org/10.1126/science.1244693

Keith, D.A., Ferrer-Paris, J.R., Nicholson, E. Kingsford, R.T., eds. *2020. The IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups. Gland, Switzerland: IUCN.*

Khan, Z., Thompson, I., Vernon, C. R., Graham, N. T., Wild, T. B., Chen, M. *(2023). Global monthly sectoral water use for 2010–2100 at 0.5 resolution across alternative futures. Scientific data, 10(1), 201.* https://doi.org/10.1038/s41597-023-02086-2

Kuzma, S., M.F.P. Bierkens, S. Lakshman, T. Luo, L. Saccoccia, E. H. Sutanudjaja, and R. Van Beek. *(2023). Aqueduct 4.0: Updated decision-relevant global water risk indicators. Technical Note. Washington, DC: World Resources Institute.* https://doi.org/10.46830/ writn.23.00061

Langhorst, T., Pavelsky, T. *(2023). Global observations of riverbank erosion and accretion from Landsat imagery. Journal of Geophysical Research: Earth Surface, 128(2), e2022JF006774.* https://doi.org/10.1029/2022JF006774

Lehner, B., Grill, G. *(2013). Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15), 2171-2186.* https://doi.org/10.1002/hyp.9740

Maggi, F., Tang, F. H., la Cecilia, D., McBratney, A. *(2019). PEST-CHEMGRIDS, global gridded maps of the top 20 crop-specific pesticide application rates from 2015 to 2025. Scientific data, 6(1), 170.* https://doi.org/10.1038/s41597-019-0169-4

Mekonnen, M. M., Hoekstra, A. Y. *(2015). Global gray water footprint and water pollution levels related to anthropogenic nitrogen loads to fresh water. Environmental science technology, 49(21), 12860-12868.* https://doi.org/10.1021/acs.est.5b03191

Messager, M. L., Lehner, B., Grill, G., Nedeva, I., Schmitt, O. *(2016). Estimating the volume and age of water stored in global lakes using a geo-statistical approach. Nature communications, 7(1), 13603.* https://doi.org/10.1038/ncomms13603

Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N., Foley, J. A. *(2012). Closing yield gaps through nutrient and water management. Nature, 490(7419), 254-257.* https://doi.org/10.1038/nature11420

Müller, G., Middelburg, J. J., Sluijs, A. *(2021). Introducing GloRiSe–a global database on river sediment composition. Earth System Science Data, 13(7), 3565-3575.* https://doi.org/10.5194/essd-13-3565-2021

Stelzer, K., Simis, S., Selmes, N., Muller, D., Politi, E. *2024 Copernicus Global Land Operations "Crysophere and Water" CGLOPS-2: Product user manual (100m). Issue v2.0.0_I1.02.* https://land.copernicus.eu/en/technical-library/product-user-manual-lake-water-quality-100m-version-2.0

The Nature Conservancy (TNC). *2009. Global database of freshwater invasive species. Unpublished.*https://databasin.org/datasets/11a22d0ce62142258baaa1cbaf520fb2/

Wang, X. Feng, L. *(2022). Global annual lake ice phenological dataset 1861-2099. Figshare. Dataset.* https://doi.org/10.6084/m9.figshare.19424801.v1

West, P. C., Gerber, J. S., Engstrom, P. M., Mueller, N. D., Brauman, K. A., Carlson, K. M., ... Siebert, S. *(2014). Leverage points for improving global food security and the environment. Science, 345(6194), 325-328.* https://doi.org/ 10.1126/science.1246067

Woolway, R. I., Sharma, S., Weyhenmeyer, G. A., Debolskiy, A., Golub, M., Mercado-Bettín, D., ... Jennings, E. *(2021). Phenological shifts in lake stratification under climate change. Nature communications, 12(1), 2318.* https://doi.org/10.1038/s41467-021-22657-4

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