# Embedding lakes into the global sustainability agenda

Protecting and restoring ecosystems to deliver global scale socio-economic benefits

White Paper prepared by the United Nations Environment Programme coordinated World Water Quality Alliance – Ecosystems Workstream

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This report has been prepared by the World Water Quality Alliance (WWQA) Ecosystems Workstream as a contribution to the work of the United Nations Environment Programme (UNEP) in their implementation of United Nations Environment Assembly (UNEA) Resolution 3/10 on "Addressing water pollution to protect and restore water-related ecosystems" (UNEP/EA.3/Res.10). The report has been prepared following a peer review process and represents the views of the authors. The report does not necessarily reflect the opinions or policies of contributing organisations.

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# About the World Water Quality Alliance

The United Nations Environment Assembly (UNEA) Resolution 3/10 on "Addressing water pollution to protect and restore water-related ecosystems" (UNEP/EA.3/Res.10) requested that UNEP develop a global water quality assessment in collaboration with UN-Water and relevant stakeholders by UNEA-5. During the inception meeting for the assessment, around 50 organisations (UN, research, civil society, private sector) who had expressed interest to engage in the assessment, also expressed interest in working with UNEP to co-design agendas and action around emerging issues. This group formed the World Water Quality Alliance (WWQA), a voluntary, global multi-stakeholders network, pooling expertise on water quality science and technology innovation. Together, they address priority topics relevant to assessment of water quality, water governance, scalable solutions for water quality and monitoring emerging pollutants serving countries throughout the lifetime of the 2030 Agenda for Sustainable Development and beyond. The UNEP Global Environment Monitoring Systems Unit hosts the WWQA Coordination Team. At the time of writing, the WWQA comprised 16 Workstreams with guidance from a Strategic Advisory Committee and a Technical Advisory Committee. Through these Workstreams the WWQA aims to provide a participatory platform for engagement on water quality issues, connecting data to action and the co-design of tailored and demand-driven services advocating the central role of freshwater quality in achieving prosperity and sustainability, raising awareness on key topics around water quality.

The WWQA Ecosystems Workstream is led by a core group from UK Centre for Ecology and Hydrology (CEH), IHE Delft Institute for Water Education, World Bank Group, Wageningen University & Research (WUR), UNEP, and the European Commission's Joint Research Centre (JRC). WWQA Ecosystems works directly with a Global Community of Practice convened by the workstream to accelerate protection and restoration of ecosystems impacted by water quality degradation. The WWQA Ecosystems mission currently focusses on addressing water quality impacts on lakes and their communities, with a view to expanding this mission to include other impacted ecosystems in coming years. It works to: (i) provide evidence to enhance the development of freshwater restoration and protection programmes globally, (ii) raise awareness of opportunities to deliver multiple socio-economic and environmental gains through effective restoration, and (iii) support developing economies where data are sparse and the societal impacts of ecosystem degradation are felt most acutely.

WWQA
World Water Quality Alliance
ECOSYSTEMS Workstream

# Executive Summary

This White Paper calls for international policy makers to consider a new sustainable approach to lake management, with ecosystem protection and restoration at its core.

'Lakes' come in many shapes and sizes, from small urban ponds, through constructed reservoirs, to the largest transboundary lakes. Collectively, these ecosystems are critical in supporting many societal needs. These include the provision of food and clean water, navigation, achieving Net Zero Carbon climate ambitions and renewable energy production, reversing biodiversity loss, delivering national and international food and non-food trade objectives, supporting livelihoods and creating jobs.

The White Paper highlights that the current environmental status of lakes is one of large-scale degradation, threatening their societal and economic value and incurring significant loss and damage. One of the main pressures facing lake restoration practitioners globally is nutrient pollution from agriculture and wastewater, although effects of climate change, plastic pollution, hydrological alteration, industrial waste discharges, invasive species infestations, and habitat destruction are also prevalent.

The current global approach to lake management is inadequate. Local to global management responses remain fragmented, under-resourced and undervalued. If left unchecked, societal impacts are predicted to substantially worsen in the coming decades. Global analyses project that by 2050 these impacts will include a decrease in the value of ecosystem services (currently estimated at USD 3 trillion) by up to 20%; a doubling (at least) of nutrient pollution from agriculture and wastewater, costing hundreds of billions of dollars per year to address; increased methane emissions from lakes with global societal costs estimated in the trillions of dollars; and a further increase in the rate of biodiversity loss from freshwater ecosystems, which is already higher than in any other biome.

The Global Community of Practice convened by the WWQA Ecosystems Workstream offers decades of expertise in implementing ecosystem restoration programmes in lakes. This know-how offers a 'game-changing' opportunity to deliver on international ambitions for 'nature-positive' ecosystem restoration (e.g. CBD COP15). Many solutions provide multiple benefits that are currently underrepresented or fragmented in existing environmental policy, limiting up-scaling and uptake. For example, Sustainable Lake Management may be considered in the context of Natural Climate Solutions. Nutrient management delivers benefits for food and water security, that can reduce greenhouse gas emissions from water bodies and land, enhance terrestrial and freshwater biodiversity, and help build adaptive capacity to the impacts of climate change.

International recognition of the need for global action on sustainable lake management is growing. This includes United Nations Environment Assembly (UNEA) Resolution UNEP/EA.5/Res.4 on Sustainable Lake Management, and a raft of related UNEA Resolutions and international initiatives focused on globally pervasive environmental pressures (e.g. on nitrogen and plastics) and sustainable management and 'nature-positive' approaches (e.g. UN Decade; CBD COP15). Collectively, these recognise that key drivers of ecosystem degradation have international dimensions in addition to local, regional and national ones. A coordinated international response is required to address them, reverse degradation and loss, and promote ecological restoration.

We propose that such an international response for lakes should be focused around a new integrative approach towards Sustainable Lake Management. We advocate a move towards an approach that delivers 'ecological net gain' or 'nature positive' outcomes from catchment to global scales, whilst recognising environmental and socio-economic co-benefits across the full sustainability policy arena.

# 4
# actions to accelerate sustainable lake management

## 1 Build capacity in monitoring and assessment

- Improve global coverage of long-term lake monitoring networks
- Accelerate integrated open-data sharing
- Support national monitoring and assessment programmes

## 2 Embed lake management in national policies

- Develop National Lake Recovery Plans
- Establish an International Centre for Innovation and Knowledge Exchange for sustainable lake management

## 3 Foster green finance partnerships

- Establish a Global Green Finance Fund for Lakes
- Increase funding for capacity development in disaster response

## 4 Raise global awareness on the benefits of change

- Implement a global communication campaign
- Establish a Global Coalition for Lakes.

**Above.** Building on the UNEA Resolution on 'Sustainable Lake Management' (UNEP/EA.5/Res.4), we propose Four Key Actions for consideration by all countries, recognising that: (1) Monitoring to guide management is key, but often restricted through limited resources and capacity, (2) Adaptive planning cycles are established in some countries and regions whereas in others they are absent, (3) Finance for nature approaches have seen much innovation in recent years and represent an opportunity to accelerate lake restoration globally, and (4) Effective outreach and communication at local, national and international scales is urgently needed.

# 1

# Introduction

This White Paper calls for a new and more sustainable approach to lake restoration, with ecosystem protection and restoration at its core. We propose a new integrative definition of Sustainable Lake Management as coordinated long-term adaptive management resulting in ecosystem protection and restoration whilst delivering environmental and socio-economic benefits beyond the scale of intervention.

Lakes and reservoir ecosystems are undervalued, understudied and often overlooked. Yet, they are of crucial importance for food security, the provision of clean water for drinking and irrigation, energy production, navigation, recreation and biodiversity. The global value of freshwater ecosystem services is in the order of trillions of dollars (Costanza et al., 2014). The importance of exposure to nature in managing mental health and improving well-being is also becoming increasingly apparent. For example, access to 'blue-green spaces', including lakes, reduced mental health impacts of severe lockdown during the COVID-19 pandemic (Pouso et al., 2021).

This White Paper focuses on natural freshwater lakes, whilst also considering man-made reservoirs. We note that the evidence base available for very small waterbodies (i.e. urban and rural ponds) is emerging, indicating that they are no less important in supporting biodiversity, carbon storage and amenity value, in relation to larger ecosystems.

**Left.** Photograph of children of the Emberá swimmng in Gatun Lake, Panama. Image credit: Bryan Spears.

Using satellite imagery, it is now possible to map and monitor the extent of lakes on earth. The Global Water Body Database, provides information on about 117 million lakes (> 0.002 $km^2$ surface area), covering 5 x 106 $km^2$ of the earth's surface, 3.7% of the non-glaciated surface area (Verpoorter et al., 2014). About half of all lakes (one quarter the global lake surface area) are located above 60°N and large lakes account for only 0.05% of lake number, but over half the global lake surface area (Pi et al., 2022).

Despite containing just 0.8% of total global non-frozen terrestrial water volume (Messager et al., 2016), nearly one billion people live within 5 km of a lake (Kummu et al., 2011). In 2020, 122 million people were reliant on untreated surface drinking water sources globally; ranging from 0% of the population in Europe and North America to 7% and 23% of the populations in Sub-Saharan Africa and Oceania, respectively (WHO et al., 2022). These populations are at immediate risk of exposure to water-borne diseases, toxins and harmful chemicals.

That is not to say that the 7 billion people reliant on 'Basic' or 'Safely Managed' supplies will be unaffected by poor drinking water quality. Sudden drinking water supply disruptions to large urban centres have been reported, for example, in response to harmful algal blooms in Lake Erie and Lake Taihu (i.e. 0.5 million people affected in Toledo, USA, 2014 (EPA, 2018) and 4 million people affected in Wuxi City, China, 2007 (Qin et al., 2010)). These reports, and a growing number of others (e.g. contamination of Guandu Lagoon, Rio de Janeiro, Brazil, water supply to >8 million people; Bacha et al., 2022) present a stark warning of the public health risks and wider economic costs caused by complacency on addressing water pollution.

It is of growing concern that lake degradation continues to be reported globally. One fifth of the world's river basins (including lakes, reservoirs and rivers) are experiencing above-normal changes in available surface water (UNEP, 2021c). The loss of species and their habitats is recognised as an international crisis, particularly in freshwater where threats of species extinctions are greater than any other major ecosystem type (estimated as an average 84% decline in populations of freshwater species over the last half century; WWF, 2022). The causes of this biodiversity loss are many, including habitat destruction or alteration (e.g. hydroelectric dam construction, shoreline development), mining, invasive species spread, and nutrient pollution. Rarely do these pressures act in isolation, and climate change likely exacerbates their effects, and complicates their management.

The degradation of water quality and biodiversity caused by nutrient (phosphorus and nitrogen) pollution is termed eutrophication and is one of the most pervasive pressures impacting lakes. Eutrophication is characterised by harmful algal blooms, habitat destruction and biodiversity loss, mass mortality events (e.g. of fish), high methane emissions, and large-scale economic loss and damage. These conditions are estimated to impact, to varying degrees, over 40% of the world's lakes (Bartram & Ballance, 1996). Between 2002 and 2010, phosphorus pollution in almost 40% of the world's river basins (estimated to contain 90% of global population) exceeded capacity for healthy ecosystems (Mekonnen &

Hoekstra, 2018). This study and others suggest that the planetary boundary for phosphorus has already been passed with respect to freshwater eutrophication (Carpenter & Bennett, 2011). Indeed, algal bloom frequency and intensity have increased in many regions (especially Asia, South America and Africa) since the 1980s, but decreased in others since 2000, possibly indicating the effectiveness of environmental regulation (e.g. North America; Fang et al., 2022).

Eutrophication is projected to increase by 20–100% by 2050 (up to 390% by 2100), under 'business-as-usual' climate and population growth projections (Downing et al., 2021). Although not fully represented in national greenhouse gas emissions reporting (i.e. under IPCC), by 2100, methane emissions from lakes and reservoirs resulting from eutrophication could reach 38–53% of current fossil fuel emissions (Downing et al., 2021).

The impacts of waste discharges from contemporary practices or legacy landfills (e.g. plastic pollution; industrial and domestic wastes) are relatively understudied, but of growing concern, as too are a wide range of emerging or understudied contaminants (e.g. Per – and polyfluoroalkyl substances (PFASs), eWastes, agrochemicals and pharmaceuticals).

This White Paper sets out the evidence-base to demonstrate that sustainable lake management will deliver multiple environmental and socio-economic benefits in a world subject to a changing climate. It recognises the need to move away from reductionist single-ecosystem, traditional restoration approaches and towards a nature-positive approach, designed to build ecological complexity and resilience across networks of ecosystems.

We review effective lake restoration approaches, identifying factors responsible for success and failure. We present the real-life challenges facing practitioners that must be overcome if local and global sustainability ambitions are to be achieved. Here we draw on expertise from over 60 countries gathered from the WWQA Ecosystems Global Survey of Lake Restoration Practitioners. Finally, we propose opportunities for greater coordination based on perspectives from the global community tasked with developing and implementing relevant sustainability or restoration initiatives.

Momentum on the needs and opportunities for ecosystem restoration on a global scale is at its highest point in history. The UN Sustainable Development Goals (SDGs), the UN Decade on Ecosystem Restoration, and the Global Biodiversity Framework provide complementary mechanisms for change (see Fig. 1 for contribution of lakes to the SDGs).

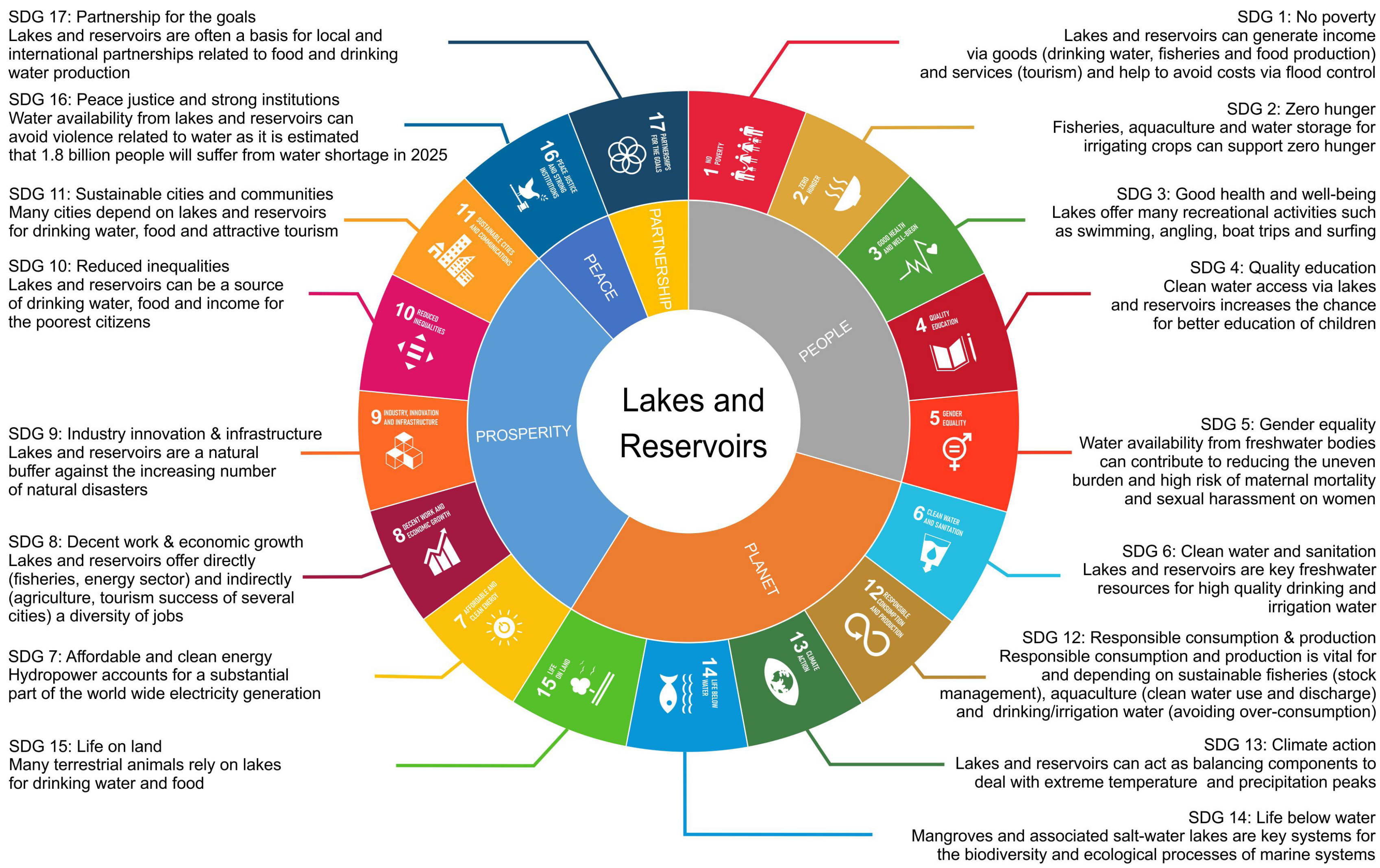


**Figure 1.** Summary of the contribution of healthy lakes and reservoirs in supporting the achievement of the Sustainable Development Goals (SDGs). Source: Ho & Goethals (2019, 2021). Healthy waters underscore many of the UN SDGs. In its recent report on delivering SDG indicator 6.3.2. UNEP (2021) states that '...quite likely for most countries, reducing nutrient release and transport will have the greatest positive impact on water quality.'

# Why Global Action on Lakes?

Reversing global biodiversity loss in lakes whilst also ensuring the delivery of essential ecosystem services requires transformative global action, recognising that many drivers of ecosystem degradation are international in scope (Box 1, Fig. 2). There is no global policy specific to lake management. Where policies exist, they mostly consider catchment to national scale targets (e.g. USA's Clean Water Act, China's 'Water Pollution Prevention and Control Action Plan'), with a few exceptions at the regional scale (e.g. the European Water Framework and Habitats Directives and the Strategic Action Plan for the Lake Victoria Basin). Policies that aim to protect freshwater biodiversity are rarely implemented with conviction. Enforcement and investment in management of lakes as a resource for people almost universally neglects the biodiversity that they contain (Darwall et al., 2018).

Major relevant global ambitions and international agreements on ecosystem restoration include:

- The UN Resolution on The Human Right to a Clean, Healthy and Sustainable Environment (A/HRC/RES/48/13 adopted 18th October 2021). This calls on States to build capacities for the efforts to protect the environment in order to fulfil their human rights obligations and commitments, and to enhance cooperation with other States, the Office of the United Nations High Commissioner for Human Rights, the rest of the United Nations system and other relevant international and regional organizations, agencies, convention secretariats and programmes, and relevant non-State stakeholders, including civil society, national human rights institutions and business, on the implementation of the right to a clean, healthy and sustainable environment, in accordance with their respective mandates;
- The UN 2021-2030 'Decade on Ecosystem Restoration' (UNGA Resolution A/RES/73/284 adopted 1 March, 2019). This aims to restore degraded ecosystems, enhance restoration efforts to promote resilience to climate and anthropogenic change, and reverse biodiversity loss through both preventive (passive) and adaptive (active) restoration measures (e.g. IPCC, 2019);
- Numerous targets from the Convention on Biological Diversity (CBD) Global Biodiversity Framework 2030 (CBD, 2022), adopted in December 2022, call for sustainable management and restoration, including Target 2: Ensure that by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity; and,
- The UN SDGs, in particular UN SDG 6 Clean Water and Sanitation. This includes a number of directly relevant targets with a deadline for delivery of 2030:

- *SDG 6.1 – achieve universal and equitable access to safe and affordable drinking water for all;*
- *SDG 6.3 – improving water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally;*
- *SDG 6.6 – protecting and restoring water-related ecosystems, including … rivers, aquifers and lakes;*
- *SDG 6.A – expanding international cooperation and capacity-building support to developing countries; and*
- *SDG 6.B – support and strengthen the participation of local communities for improving water and sanitation management.*

International recognition of the need for global action on specific environmental issues that may benefit lakes is apparent across a raft of United Nations Environment Assembly (UNEA) Resolutions. UNEA Resolutions are not legally binding, but, they represent current collective thinking on prevailing environmental issues, build consensus and are a vital first step in the need for action needed to achieve these global ambitions. Notable relevant UNEA Resolutions for lakes include Resolution 5/4 on Sustainable Lake Management (UNEP/EA.5/Res.4), building on Resolution 3/10 on Addressing Water Pollution to Protect and Restore Water-Related Ecosystems (UNEP/EA.5/Res.10).

Other relevant resolutions call for sustainable management of natural resources, pollution reduction, and ecosystem restoration including on Sustainable Nitrogen Management (UNEP/EA.5/Res.2), Mineral Resources Governance (UNEP/EA.4/Res.19), End Plastic Pollution: Towards an International Legally Binding Instrument (UNEP/EA.5/Res.14); Nature-based Solutions for Supporting Sustainable Development (UNEP/EA.5/Res.5); and, Conservation and Sustainable Management of Peatlands (UNEP/EA.4/L.19), among others.

The global challenge now is to embed sustainable lake management across this complex landscape of targets and policy drivers. Calls have been made for new indicators to aid this process. For example, addressing biodiversity loss may require integration of relevant targets, indicators and projections, analogous to the UNFCC 1.5 to 2°C approach (Mace et al., 2018). Sustainability indicators have been proposed to support lake management framed around relevant UN SDGs (Ho & Goethals, 2019). However, we highlight an opportunity to extend these approaches to ensure that new policy relevant targets are set from catchment to global scales on e.g. societal benefits, climate regulation, and Net Zero Carbon ambitions. The UN 2023 Water Conference, the Water Action Decade Acceleration Framework, and the CBD Global Biodiversity Framework 2030 will be important drivers of increased international ambitions on sustainable lake management.

# Box 1. Lakes under Stress in the Anthropocene

Jenny et al. (2020) review the complex picture of multiple stressors impacting lakes and reservoirs globally. The impacts described include algal blooms and dead zones, mass species mortalities, biodiversity loss, and, changes in food web structure. The causes of these impacts are diverse and vary among countries. However, the most pervasive threats include overexploitation of resources (water and food), inputs of excess nutrients leading to harmful algal blooms, changing climate, overfishing, species invasions, infectious diseases, expanding hydropower, acidification, contaminants, emerging organic pollutants, engineered nanomaterials, microplastic pollution, artificial light and noise, freshwater salinisation, and the cumulative effects of multiple stressors. These threats and their effects on a hypothetical lake ecosystem are considered in Figure 2. White arrows highlight direct or indirect impacts on the lake food web.

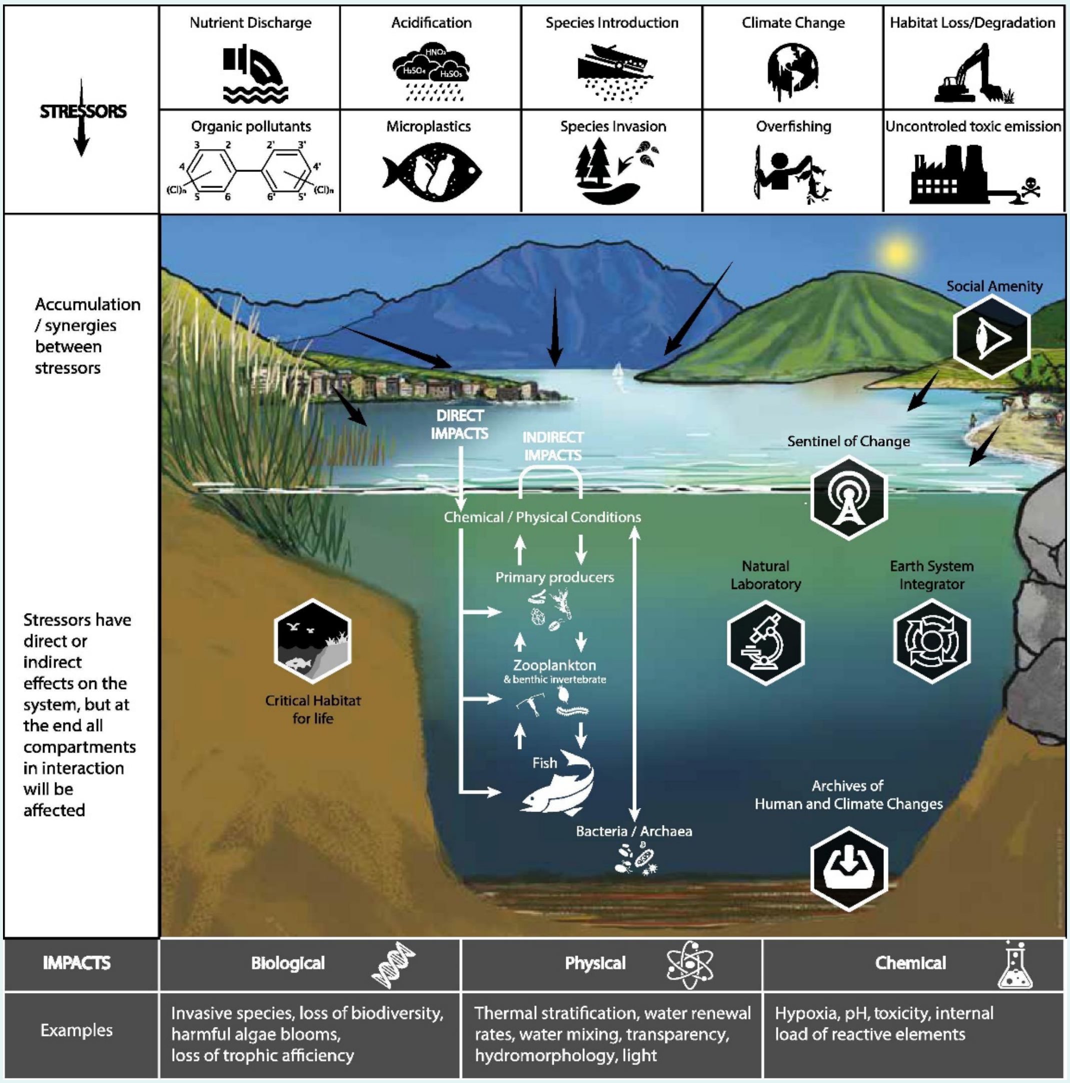


**Figure 2.** The many stressors and impacts acting on lakes in the Anthropocene (from Jenny et al., 2020).

# The Global Environmental Status of Lake Degradation

Population increase and over-exploitation of natural resources (e.g. overuse of fertilisers in agriculture, wastewater discharges, industrial fishing, water abstraction, and hydroelectric dams) are important drivers of lake degradation (Ho & Goethals, 2019). Declining ecosystem health means negative effects on fish and other species, the spread of invasive species, proliferation of harmful algal blooms that can be poisonous when ingested, and high pathogen and toxic chemical loads (Box 1). However, evidence on the extent and intensity of pressures at the global scale is lacking due to inconsistent or non-existent monitoring and regulation across many countries (UNEP, 2021a & 2021b; Box 2). Thus, we rely largely on long-term monitoring programmes of sentinel lakes to detect the causes and speed of ecosystem degradation and on large scale modelling of pressures to provide an indication on the global status of lake degradation (reviewed below).

The scale of global ecosystem services loss associated with lake degradation makes bleak reading in the scientific literature and substantiates the view that we are in a dangerous phase of ongoing decline (Box 1). Through long-term international scientific collaboration, we know that lake water quality and ecology are inherently linked and both are sensitive to environmental change (e.g. Box 1). One particular challenge is ensuring that current policy is informed by this scientific understanding, so-called evidence-based policy development. Key considerations in this respect include:

- Future projections indicate that lakes and reservoirs will be increasingly sensitive to interactions among stressors (Birk et al., 2020), and that this could be accounted for in national management planning (Spears et al., 2021);
- Of particular concern are the combined effects of both nutrient pollution and climate change, as reviewed by Meerhoff et al. (2022). These authors report that interactions between nutrients and climate change may mean that current water quality targets may no longer be relevant. However, consideration of climate change resilience is conspicuously absent in most lake management plans;
- Lakes are now known to play an important role in the earth's climate systems through regulating carbon burial and emissions of greenhouse gases (Meerhoff et al., 2022), yet, they are largely absent from Net Zero Carbon plans, including Nationally Determined Contributions or Adaptation Plans, under the Paris Agreement (UNFCCC, 2016);
- Lakes (especially shallow ones) may exhibit sudden ecosystem collapse due to environmental stress, and this can drive economic losses in socio-ecological systems (Dasgupta, 2021), however, these relationships are not yet widely recognised in established ecosystem restoration initiatives; and

- Smaller lakes and ponds may make a disproportionately large contribution to global lake ecosystem services, suggesting that targeting networks of smaller water bodies (i.e. 'Lake Districts' or 'Waterscapes'; Heino et al., 2021) may deliver significant benefits relative to focussing resources on a few large lakes.

We review below some contemporary evidence placing the degradation of lakes and reservoirs at the centre of multiple major global sustainability challenges.

## Counting the Societal Cost of Lake Degradation

- Costanza et al. (2014), acknowledging a high degree of uncertainty, use a unit estimate of USD 12,512 and a surface area estimate of 220 million hectares for freshwater (i.e. rivers and lakes) to produce a value estimate of USD 2.8 trillion per year for 2011 (as 2007 USD). Following this approach and using surface area estimates for all natural lakes (267 million hectares) and constructed reservoirs (26 million hectares; Messager et al., 2016) with surface area greater than 10 ha, we estimate their global ecosystem services values to be USD 3.1 and USD 0.3 trillion per year, respectively;
- Costanza et al. (2014) estimate that meeting the UN SDGs would increase by 18% the value of freshwater ecosystem services by 2050. If we continue on the current unsustainable path (i.e. business as usual scenario) then the value of freshwater ecosystem services is predicted to decline by 20%, by 2050;
- The losses and management costs caused by eutrophication of freshwaters in the USA were estimated at USD 2.2 billion annually, covering losses to industry, real-estate, and management for conservation of endangered species and drinking water supply (Dodds et al., 2009). Similar costs in other countries include USD 208 million for Spain, USD 371 to USD 695 million for the Netherlands, and USD 116 to USD 155 million for Australia (Moxey, 2012). In the UK, warming may increase such costs from £173 million (2018; USD 220 million per year) to >£400 million in the next 40 years (Jones et al., 2020);
- On a global scale, dealing with cyanobacterial blooms has resulted in billions of dollars of new investment in water treatment plants and recurrent operational costs (Hamilton et al., 2014); and
- Many of the costs above cannot directly be translated to economic loss. The above costs do not include global societal costs associated with greenhouse gas emissions from lakes. Downing et al. (2021) estimate the present value global social cost of eutrophication-driven methane emissions from lakes between 2015 and 2050 at USD 7.5– USD 81 trillion.

## Nutrient Pollution, Water Quality and Food Security

- Nutrient pollution is one of the greatest threats to water quality globally, with 40% of the world's lakes estimated to be impacted (Bartram & Ballance, 1996). Phosphorus and nitrogen losses from agriculture and waste water discharges to freshwater are estimated to have increased in the 20th century from 5 to 9 million tonnes per year and 34 to 64 million tonnes per year, respectively (Beusen et al., 2016);

- By 2050, phosphorus fertiliser use in croplands is projected to at least double (cf. 2010) to meet food and feed demands (Mogollón et al., 2018) and losses of phosphorus from wastewater to freshwaters are expected to increase up to 70% by 2050 (van Puijenbroek et al., 2019);
- Driven by the growing demand from 20% of the global population reliant on fish for protein (FAO, 2016), inputs of phosphorus from inland water aquaculture are projected to further increase from current estimates of 0.94 million tonnes per year (Ahmed et al., 2019);
- Nutrient pollution is driven by national to global scale trade (Hamilton et al., 2018) and the environmental impact is also traded across borders, from producer to consumer; and
- National Sustainable Nutrient Plans are being developed to increase recycling from waste streams and lower reliance on imported mineral fertiliser, in part to relieve stress on ecosystems whilst reducing exposure to fertiliser price volatility (Cordell et al., 2022).

## Balancing Lakes in the Earth's Climate System

- Holocene lake sediments are estimated to contain 820 billion tonnes of buried organic carbon worldwide compared with 1,395 billion tonnes carbon storage in terrestrial soils (Tranvik et al., 2009);
- Greenhouse gas emissions from lakes are estimated to be in the order of 20% of current global fossil fuel emissions (Del Sontro et al., 2018; Downing et al., 2021). Emissions from lakes occur predominantly as methane (current emission of 4.8 to 8.4 billion tonnes $CO^{2}$-eq per year; Downing et al., 2021), which increase with nutrient enrichment, climate warming, and the installation of dams (Beaulieu et al., 2019; Davidson et al., 2018). High organic matter pollution (e.g. from untreated sewage) causes extremely high methane emissions from lakes (e.g. Bangalore (Bengaluru), Karnataka, India; Pickard et al., 2021), indicating the importance to expand secondary wastewater treatment;
- Eutrophication in lakes is projected to increase by 20 – 100% by 2050 and by up to 390% by 2100, by which point methane emissions from lakes will be similar to present day carbon burial by marine or terrestrial ecosystems; and
- Currently, only emissions from flooded lands are considered in national IPCC Reporting Inventories, despite the evidence of globally significant emissions from lakes (Meerhoff et al., 2022). Lake management measures may be selected to enhance carbon burial and reduce atmospheric emissions (Taylor et al., 2019), creating new opportunities for Climate change Adaptation Planning.

## Lakes and Freshwater Biodiversity Decline

- The loss of species and their habitats constitutes an international crisis, particularly in freshwater ecosystems. The Living Planet Index indicates a decline in species population of 84% since 1970; a rate of 4% per year biodiversity loss (WWF, 2022). This includes an 88% decline in populations of freshwater megafauna including species of sturgeon, crocodilians, giant turtles, and amphibians (He et al., 2019);
- Attention on freshwater biodiversity conservation lags behind terrestrial ecosystems (Abell et al., 2011), despite calls for more concerted action (Bunn, 2016; Darwall et al., 2018; Dudgeon, 2010; Millennium Ecosystem Assessment, 2005; Russi et al., 2013);
- Many large lakes are over-exploited by commercial and artisanal fisheries, particularly in the Global South (Lynch et al., 2017; Magqina et al., 2020), affecting ecological community structure and food-web stability, and the control of diseases (Madsen & Stauffer, 2011);
- Degraded lakes are particularly vulnerable to invasive species such as water hyacinth, which now chokes water bodies throughout Asia and Africa, further reducing options for livelihoods (May et al., 2021);
- The combined effect of warming and increasing nutrient pollution is leading to increased anoxia in lakes, with oxygen running out at up to 9 times the rate reported for the world's oceans (Jane et al., 2021). In a 3.2°C warmer world, 36% of the world's freshwater fish species will experience climate extremes in half of their geographical range (Barbarossa et al., 2021), increasing the risk of mass mortalities (e.g. of fish and amphibians), reports of which appeared to increase over the last 50 years (Fey et al., 2015); and,
- Plastic pollution is not just a 'marine problem'. Recent estimates suggest that between 19 and 23 million tonnes of plastic entered aquatic ecosystems in 2016 (11% of global plastic waste production), and annual loads could reach 90 million tonnes by 2030, based on current waste management trajectories (Borrelle et al., 2020);
- Estimates of contemporary loads to the global ocean are variable (e.g. ~0.8 to 2.7 million tonnes (Meijer et al., 2021) and ~9 million tonnes (Jambeck et al., 2015). No reliable estimates of loads to lakes are currently available, despite the high likelihood that lakes will retain plastic pollution on route from land to sea;
- The few assessments conducted on individual lakes agree generally with this global trend and indicate that plastic pollution of lakes is a widespread and significant concern (e.g. Tonle Sap Basin, SEA; Finnegan & Gouramanis, 2021; Great Lakes, NA; Cable et al., 2017); and
- Harmonised monitoring approaches have been developed to address the current lack of global data for lakes on plastic pollution (UNEP, 2020).

## Chemical Cocktails Confound Zero Pollution

- Novel chemicals or chemical mixtures (e.g. Spears et al., 2022; www.ewastemonitor.info) lack robust regulatory assessments. For example, of the ~23,000 chemicals registered in the EU, about 80% lack regulatory risk management assessments (Persson et al., 2022);
- Industrial waste discharges (e.g. mining or mineral processing waste waters) often involve complex mixtures of chemicals that can persist in lakes at low concentrations for decades (Olszewska et al., 2017). A similar scenario exists for domestic wastes (e.g. pharmaceuticals and PFAS). The ecological or human health effects of long-term exposure to water or food contaminated with low concentration chemical mixtures is difficult to determine;
- Pollution events at the river basin scale are worryingly common, leaving a pollution legacy in lakes and reservoirs. Examples include industrial waste discharges in the Minas Gerais region, Brazil, 2019 (13 million cubic metres of iron-ore waste to the Paraopeba Basin reaching the Atlantic), and in Ajka, Hungary, 2010 (1 million cubic metres of 'red mud' waste eventually reaching the Danube Basin) (Fig. 3);
- An emerging concern is the impact of wastewater discharges from the electronics sector, so called eWastes. About 82% (44.3 million tonnes) of the global eWaste stream remains undocumented, but much may be disposed of in local land-fill or traded to developing economies for disposal, where it may enter surface waters through leachates (Forti et al., 2020); and
- Current and potential petrochemical explorations in lakes pose a direct risk to ecosystem health, including of species rich ancient lakes (e.g. oil extraction exploration across African Great Lakes, Verheyen et al., 2016).

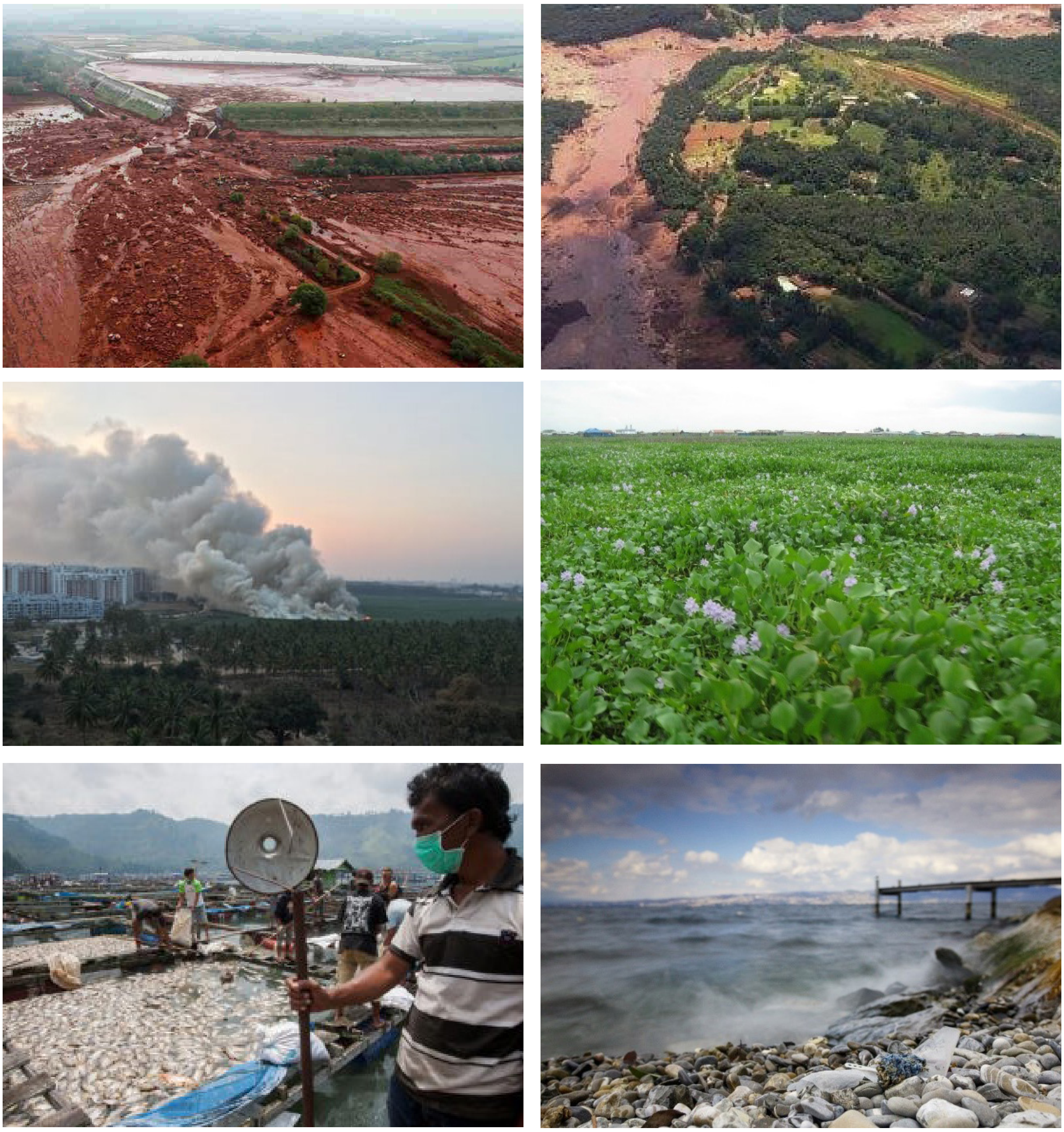

**Figure 3.** Photographs of lake degradation. From t*op-left to bottom right*: discharge of mine-tailings waste into the aquatic environment in Ajka, Hungary (*top left hand image;* photo source: www.npr.org), and Minas Gerais, Brazil (*top right-hand image;* photo source: the Minas Gerais' Fire squad, public domain); fire on Bellandur Lake in 2017, Bengaluru, India (*middle left-hand image;* photo taken by Aaditya Sood, source: www.theguardian.com); water hyacinth infestation, Lake Nokoue, Benin (*middle right-hand image;* photo taken by Ken Irving); fish kill in aquaculture cages in Lake Toba in 2016, Indonesia (*bottom left-hand image;* photo taken by Binsar Bakkara, source: https://e360.yale.edu); plastic pollution on shore of Lac Leman (L. Geneva), France (*bottom right-hand image;* photo taken by Florian Legrand, source: www.plasticoceans.org/).


2

# The Global Baseline Situation for Lake Management

The UN General Assembly Resolution (A/RES/76/300) of August 2022 on the Right to a Clean and Healthy Environment recognises access to a clean, healthy and sustainable environment to be a universal human right. This is particularly applicable to lakes and reservoirs and the multiple benefits they provide, and provides a basic motivation for restoring degraded lakes. However, efforts over the last few decades to reverse past human effects on lakes have focused mainly in North America (mostly USA and Canada), Europe (e.g. Finland, Denmark, the United Kingdom, The Netherlands, Switzerland and Germany), Australia and New Zealand, and Asia (China and Japan).

Early work in restoring alpine lakes and similar work in North America developed basic models to relate nutrient loads to concentrations and thresholds of quality (Dillon & Rigler, 1974; OECD, 1982; Vollenweider & Kerekes, 1980). Work on the restoration of shallow lakes provided valuable evidence of the reasons behind successes and also why some restoration efforts failed. Key lessons are that effective restoration depends on social acceptance of restoration interventions (and their costs), on the willingness of stakeholders to co-operate and, where necessary, for national and regional governments to have statutory instruments to monitor the environment and effectively plan and implement interventions. It is a complex process, with ecological, social, economic and regulatory aspects, all of which need to align before benefits can accrue. One tool for reducing uncertainty in any type of restoration programme is to follow a 'standards-based' approach, for example, utilising the International Principles and Standards for the Practice of Ecological Restoration (Gann et al., 2019) which provides a holistic model for planning, implementing and monitoring ecological restoration projects.

**Left.** Two boats floating in an algal bloom in Labelle, Florida, triggered by elevated phosphorus concentrations. Photograph courtesy of Adobe Stock.

Reversing ecosystem degradation requires robust evidence on the intensity and duration of pressures and their relationship with indicators of ecosystem structure and function (Kingsford et al., 2021; Lovett et al., 2007). Such relationships are central to target setting and, without them, interventions will be subject to the uncertainties of 'trial and error' and likely contentious debates on cost-effectiveness. Although evidence linking pressure reduction to improved ecosystem services are available (Grizzetti et al., 2019), assessments on the efficacy of measures to deliver against ecosystem service targets on a global scale remain uncommon. Biodiversity-based indicators developed to meet the objectives of the EU's Water Framework Directive have, for example, been linked to human health indicators for cyanobacteria (Chorus & Welker, 2021; Persson et al., 2022).

The technical know-how to detect threats and degradation of lakes and reservoirs has developed rapidly over recent decades (e.g. UN SDG Indicator 6.6.1; UNEP, 2021b). We know that recovery of lakes can be achieved through careful management of the causes of degradation, and that recovery progresses on ecosystem time-scales, of years to decades, not political ones. For example, large decreases in nutrient loading to lakes have been reported in recent decades in response to wide reaching legislation in North America, China and Europe, mainly targeting waste water treatment improvements. Despite this, nutrients are still reported as the main pressure acting, at least, on European lakes, although other stressors are clearly also important at catchment scale (Birk et al., 2020).

Knowledge on lake restoration is advanced, placing the academic community at the forefront of restoration ecology. Knowledge exchange is fostered through international academic societies including the International Society of Limnology (SIL) and the Association for the Sciences of Limnology and Oceanography (ASLO). This evidence provides a rich resource through which to critically assess the effectiveness of past restoration efforts, and to increase uptake of lake management approaches. These include global initiatives of the International Lake Environment Committee (ILEC), the SIL Working Group on Lake Restoration, the Global Environment Facility Transboundary Waters Assessment Programme (GEF-TWAP), as well as many national and catchment scale initiatives.

The GEF-TWAP conducted a major review of status and trends of the world's transboundary ecosystems, including an assessment on transboundary lakes and reservoirs (ILEC & UNEP, 2016). This work identified some 1,600 transboundary lakes and reservoirs and through assessment of 206 of these concluded that:

- Lack of uniform data makes it difficult to accurately assess the status and trends of transboundary lakes on a global scale;
- Based on their basin characteristics, the African transboundary lakes collectively exhibited the greatest (Adjusted) Human Water Security threats, followed by lakes in Asia and South America. Transboundary lakes in the developed countries exhibited the greatest 'Incident Biodiversity threats', with those in developing countries exhibiting comparatively better conditions;

- Integrated Water Resource Management (IWRM) can best manage lakes and other lentic water systems for sustainable ecosystem services within the context of an Integrated Lake Basin Management (ILBM) framework; and
- Although the activities associated with transboundary assessments can be incorporated within future programmes of UN and other international agencies to some degree, a core requirement for undertaking future assessments will be the availability of sufficient, sustainable financial resources and collaborative institutional support.

In an analysis of restoration success of wetlands (including lakes), Meli et al. (2014) showed that restoration enhances the creation and maintenance of natural habitats, biodiversity, and the provision of ecosystem services, although success was strongly influenced by the context of the situation. Lake restoration showed generally positive results compared with baseline. Despite this, the most common lake management approach, globally, focuses solely on pressure reduction targets. However, in many countries, even monitoring of the common causes of degradation remains limited. For example, UNEP (2021b) states that "…quite likely for most countries, reducing nutrient release and transport will have the greatest positive impact on water quality." Despite improvement in global models to estimate nutrient loads from land to water (e.g. Janse et al., 2015; Malagó et al., 2017) *in situ* monitoring and assessment of ecosystem health and emissions of nutrients and other pollutants to freshwaters is inadequate in many countries (Box 2).

The development and implementation of UN Sustainable Development Goal (SDG) indicators 6.6.1 and 6.3.2 (Box 2, Fig. 4) is an important first step to support national assessments of lake ecosystems. For nutrient pollution reporting under SDG 6.3.2, so far, very few lakes have been evaluated in a meaningful way (Box 2). The SDG 6.6.1. Status Report indicates no consistent global trend in two simple water quality indicators (turbidity and trophic state index) comparing status in 2017-2019 with 2006-2010 (UNEP, 2021c). Turbidity is used in SDG 6.6.1 as an indicator of potential water pollution including metals and bacteria. Of 2,300 large lakes assessed using satellite data in the SDG 6.6.1 Status Report, elevated turbidity was reported in about a quarter with the report concluding that that 21 million people, including 5 million children, were at risk of increased exposure to polluted waters. SDG 6.6.1 does not currently assess data on biological health.

## Box 2. Sustainable Development Goals and Indicator 6.3.2

Sustainable Development Goal (SDG) indicator 6.3.2 is one of 11 SDG 6 indicators that track progress towards ensuring availability and sustainable management of water and sanitation for all. To report on this indicator, countries are requested to submit information on the number of freshwater bodies (lakes, rivers and aquifers) classified as having good ambient water quality as a proportion of the total number assessed.

For lakes, classification at Level 1 is based on the measurement of five core variables (nitrogen, phosphorus, pH, salinity and dissolved oxygen) and compared with threshold target values that represent 'good ambient water quality'. A lake is only classified as having good ambient water quality if 80% or more of the measurements meet their respective targets over the reporting period. At Level 2, countries can opt to include additional variables or parameters and approaches to monitoring.

The United Nations Environment Programme (UNEP), the custodian UN Agency for this indicator, requests countries to report on a three-year cycle. To date (2023), over half of UN Member States have reported on this indicator, and in addition to valuable water quality information, this process has provided great insight into the capacity of countries to monitor and assess their freshwaters.

In addition to the output of the classification process, UNEP requests additional metadata to be reported such as the target threshold values used in the assessment, and the number of monitoring stations and monitoring values used to calculate the indicator. This additional information made clear that efforts to monitor and assess lake water quality are extremely limited globally with information on only 13,000 lakes available in 2020 (UNEP, 2021a), and even more concerning is that an analysis of countries reporting based on GDP per capita revealed that the 22 poorest countries collectively reported on only 198 lakes, or 1.5% of the total (Fig. 4).

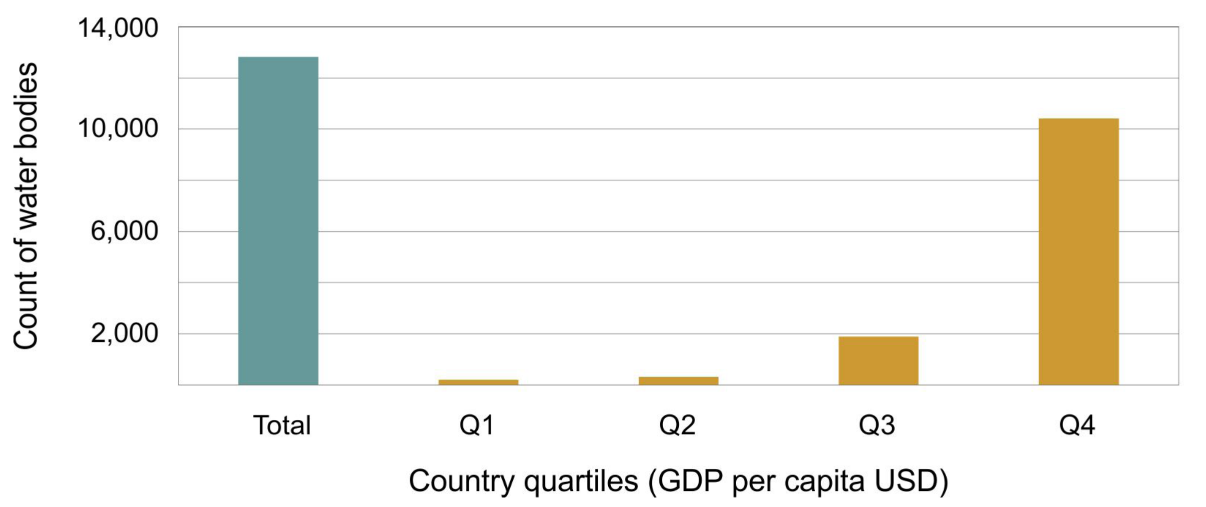


**Figure 4.** Proportion lake water bodies reported on as a proportion of the total water bodes partitioned by GDP per capita of the reporting country (Note: Q1 represents 22 poorest countries, Q2 = 20, Q3 = 28, Q4 = 26. GDP quartile bins defined by GDP of all 193 UN Member States).

## Learning from the Past to better Manage the Future

Different frameworks have been developed to support integrated lake and catchment management. These include UNEP's Framework for Freshwater Ecosystem Management (UN Environment, 2018), the Integrated Lake Basin Management framework of ILEC (Box 3, Fig. 5), and others of relevance such as the Principles for Ecosystem Restoration to Guide the United Nations Decade 2021–2030 (FAO et al., 2021). They acknowledge the need for accurate evidence to inform decisions within coordinated governance, policy, and institutional frameworks.

We can draw lessons from the implementation of established international conventions and agreements. Davidson (2018) provides an overview of biodiversity-related conventions relevant to lakes and other wetlands, as defined in The Convention on Wetlands of International Importance (The Ramsar Convention, 1971). The convention was the earliest International Agreement focused on conservation of 'wetlands', and provided the foundation for other conventions and international initiatives important for the management of lakes and reservoirs, including the Convention on Biological Diversity (Hettiarachchi et al., 2015). However, the convention is now 50 years old and, yet, has failed to stem the trend ('bend the curve') of biodiversity loss in the world's wetlands (and lakes), even those designated by Member States as Ramsar Sites. Reasons behind this range from a lack of sanctions, insufficient monitoring, and, more often than not, an absence of effective management, reporting, and relevant indicators (Bridgewater & Kim, 2021; Kingsford et al., 2021). Most important may be a general lack of political will for effective implementation of the convention (Gardner, 2018).

Lessons can also be learned from legally binding regional directives that have transformed the monitoring and assessment of lakes, but failed to meet their ecosystem management objectives. Carvalho et al. (2019) and Poikane et al. (2019; 2020) review lessons from 20 years of the EU Water Framework Directive (WFD), highlighting inconsistencies in the setting and assessment of nutrient criteria and ecological indicators, as well as insufficient monitoring, financing, and governance coordination that have limited the translation of the directive into ecological improvements. The WFD also fails to oblige Member States to consider small lakes, typically excluding urban waters and those less than 50 ha in surface area. These authors call for more consistency in approach to River Basin Management (including lakes and reservoirs within them), and better integration of water policy into other policy domains including agriculture, urban planning, land-use, flooding, climate change and energy.

To date, no coordinated monitoring and assessment of use-based indicators (i.e. ecosystem service indicators) with which to assess restoration effectiveness exists for lakes. This is despite the advent of the UN SDGs which offer a valuable framework. The baseline is such that the wider benefits of restoration interventions, beyond water quality and biodiversity enhancement, are rarely considered. So, most countries are seemingly unaware of the scale of the potential benefits of investing in lake management. These may include, for example, resource circularity, renewable energy production, food production, climate change mitigation, health and wellbeing. The baseline for lake and reservoir management is one that vastly under delivers, or, at best, is undervalued.

To build on these perspectives and to provide global context on the baseline of lake management, the WWQA Ecosystems Workstream conducted a survey of global lake restoration practitioners (Box 4; Fig. 6). The survey indicated that a range of 'Nature-based Solutions' (WWDR, 2018) are currently employed in lake management programmes globally. Measures targeting nutrient pollution reduction were perceived to be most effective, whilst those targeting species re-introduction or the control of non-native species deemed least effective. A range of ecosystem service impacts were assessed, with recreation, conservation and biodiversity, and human and animal health ranked as most impacted globally. In lower GDP countries, the impacts of pressures on fisheries, drinking water quality, and irrigation were perceived to be more severe than in higher GDP countries. There is an apparent inconsistency in the use of targets, with beneficial use, ecological, and pressure-based targets commonly employed, but not collectively or consistently. A lack of stakeholder engagement and effective governance were cited as key barriers to effective restoration across all countries. A lack of finance was also listed as a key issue in low GDP countries. The survey highlights a general lack of coordination and consistency of approach across countries. It confirms that climate change is rarely considered in target setting, and that multiple pressures are perceived to be affecting multiple ecosystem services. The relative importance of those impacts vary with economic development.

# Box 3. Key elements proposed by ILEC for Effective Lake Management

## Institutions

A management system with an appropriate organisational setup helps ensure sustainable benefits to watershed resource users.

## Policies

Policy tools must be developed to facilitate concerted societal actions for sustainable watershed management.

## Participation

Stakeholders should participate in the decision-making process for sustainable management.

## Technology (& Innovation)

Assessing the efficacy of interventions and developing novel suites of measures requires uptake of new technologies and innovation.

## Information

Without knowledge generation and sharing, human and financial resources mobilised in watershed management may prove futile.

## Finance

Financial resources should come from all stakeholders benefiting from both direct and indirect use of natural resources. Efforts must be made to develop innovative approaches for generating locally usable funds.

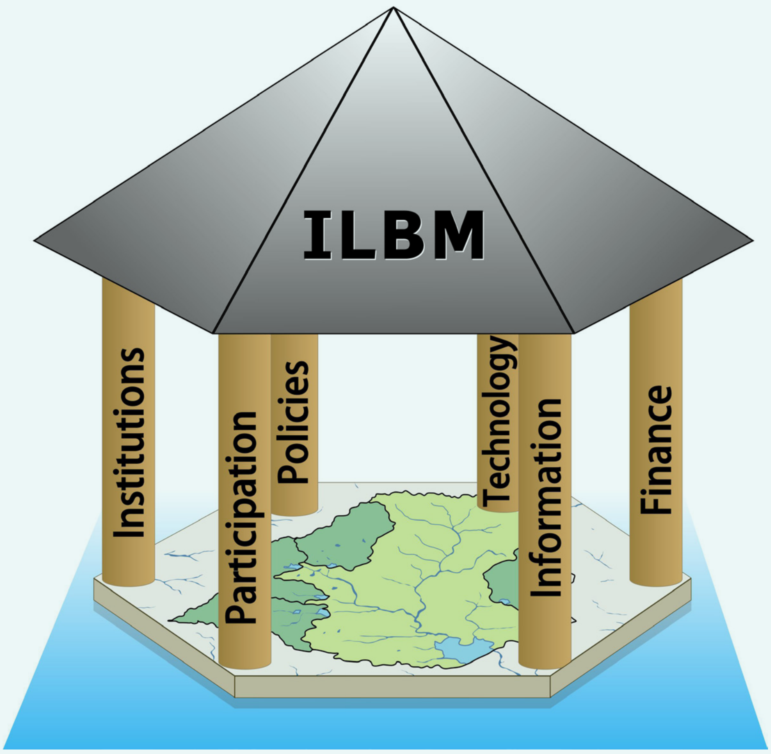


**Figure 5.** The International Lake Environment Committee's (ILEC) Integrated Lake Basin Management (ILBM) framework (ILEC, 2005) www.ilec.or.jp.

# Box 4. The Global Survey of Lake Restoration Practitioners

## Methodology and Survey Design

The Global Survey represents an overview of the experiences and opinions of practitioners, some with experience of managing a single lake, some with experience working on several lakes in a region, whilst others offered broader national or even international experiences. This collation of expert opinions is used, here, to reveal broad patterns, with care being taken not to over-interpret the results. Responses were assessed in relation to per capita GDP, using four groups: Q1 countries have the lowest per capita GDP and Q4 the highest. Per capita GDP is strongly correlated with the Human Development Index ($r = 0.95$) as used by Kirschke et al. (2020) and, together, these provide an insight into the likely capacity of countries to engage with the processes involved in lake restoration. The survey received 179 responses from over 60 countries, with a bias towards Q4 countries (Fig. 6), who contributed 58% of all respondents, mostly from Europe, North America (USA, Canada), Asia (Japan and South Korea), and Australasia (Australia and New Zealand).

## Perceived Importance of Individual Pressures

Responses to the present survey indicated moderate and severe impacts from all listed pressures, with nutrient pollution from agriculture most frequently cited, followed by climate change and hydrological alterations. All pressures are likely to be important in some lakes across all GDP classes. However, overfishing, aquaculture, industrial pollution and plastics were perceived to be more important in Q1-Q3 countries. Plastics were perceived as having relatively low importance as a pressure, albeit with greater prominence in Q1-Q3 than in Q4 countries.

## Perceived Impacts on Ecosystem Services

Recreation was the ecosystem service rated most impacted by pressures, followed by conservation and biodiversity, human and animal health and fisheries. Q4 countries dominated the 'moderate' and 'severe' responses for the services ranked as most impacted. However, for fisheries, drinking water and irrigation, half or more of these responses were from Q1-Q3 countries, suggesting that economic conditions influence how a service's importance is perceived. Several of these categories are not mutually exclusive. Fisheries, for example, may represent one element of a broader recreation ecosystem service in Q4 whilst being an important source of protein for Q1-Q2.

## Target Setting

All but 21 respondents indicated that targets existed for at least one of 'beneficial uses', 'ecological criteria' or 'pressures'. However, 70 respondents indicated that no beneficial use targets existed, 49 respondents indicated an absence of ecological targets, and 65 respondents indicated an absence of pressure-based targets. Finally, less than a third of respondents indicated that targets accounted for the effects of climate change.

## Perceived Effectiveness of Lake Management Approaches

Nutrient pollution reduction measures, both from the catchment and from legacy nutrient stores in lake-bed sediments, were perceived to be the most effective measures. This is in line with the respondents' importance of nutrient pollution (from agriculture) as the most important pressure. However, for these measures, more positive responses were received by Q4 respondents than Q1-Q3. This may reflect the high cost and relatively sophisticated governance and regulatory structures required to manage catchment-scale interventions. Species-reintroduction and the control of invasive species were viewed as being least effective, perhaps indicating that the reasons behind the loss of desirable species are nested in other stressors and that once invasive species are established, they are extremely difficult to eradicate.

## Reasons for Success and Failure

Engagement with stakeholders was identified by over half of the respondents as a key factor behind the success of restoration projects. However, additional comments supplied by respondents underlined the importance of all factors and their interlinkages. For example, it was stated that engagement can increase knowledge on how to acquire funding resources, while governance enables all steps. When explored in more detail, insufficient finance was frequently cited by Q1-Q3 countries as contributing to restoration failure. Participants commented that conventional monitoring programmes do not enable effective evidence-based decision making, that monitoring of transboundary waters is particularly problematic, and that project funding is commonly directed towards 'doing something' rather than understanding the system and predicting the effects that a restoration activity might achieve.

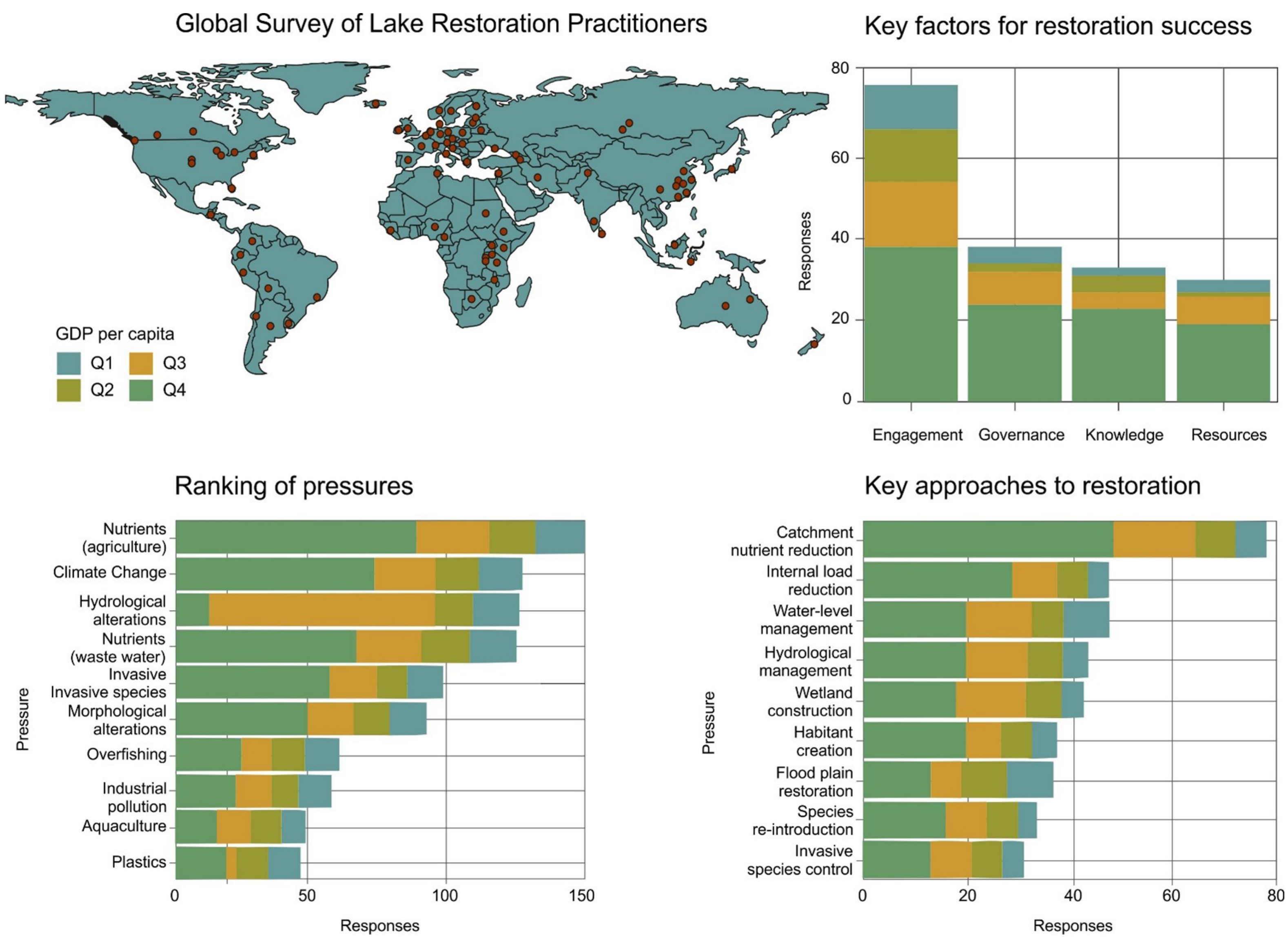


**Figure 6.** Summary infographic of WWQA Ecosystem Global Survey of Lake Restoration Practitioners.

## Broadening the Scope on Sustainability Ambitions

There is a pressing need to broaden the scope and accelerate scaling up lake management programmes within a new framework that aligns with the global sustainability agenda. Such a framework can empower countries to reach beyond traditional restoration programmes to unlock multiple benefits. We highlight the opportunity of engaging with the UN SDG framework (Fig. 1) to increase awareness across governments towards national scale reporting on status, trends and restoration plans through existing reporting cycles.

Compared with ocean ecosystems, lakes and their societal benefits have received too little emphasis in the SDGs and other global initiatives, including the UN Decade on Ecosystem Restoration. However, in the most recent Convention of the Parties (COP 15, December 2023) of the Convention for Biological Diversity (CBD), Target 2 aspires to bring by 2030, 30% of degraded terrestrial, inland water and coastal and marine ecosystems under effective restoration, in order to enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity.

Achieving CBD Target 2 will require a coordinated international response. A first step will be to develop and apply a coordinated sustainability assessment designed to map lakes across national to global initiatives, demonstrating the breadth of their contribution to society, within an established sustainability framework. UN SDG 6 Clean Water and Sanitation and the UN Decade on Ecosystem Restoration are two logical driving forces behind this action, although we recognise also the synergies between these initiatives and Net Zero for carbon and Net Zero Plus approaches.

The WWQA has already made progress towards this agenda. Two sessions at the 2021 Stockholm World Water Week on Investing for change through the World Water Quality Alliance convened 254 participants across all continents and sectors to showcase active lake restoration programmes across Chile, North America, Europe, New Zealand, India, and Africa. These case studies represent some of the world's most challenging restoration programmes, with financial investment estimated in the order of hundreds of millions of dollars. During these workshops we challenged the community to identify the Top 5 Opportunities to Change the Game on Lake Restoration in the context of the UN Decade on Ecosystem Restoration.

## WWQA Top Five Game-Changing Opportunities

### Embrace and invest in innovative evidence streams

The lack of robust evidence underpinning restoration is a long-standing concern. It was reported as a major issue following the most recent SDG indicator 6.3.2 data collection of 2020 (UNEP, 2021a) and in the previous decade in the GEF-TWAP Assessment (ILEC & UNEP, 2016). At the national scale, assessments of ecosystem health status and trends should be used to inform restoration investments. The Restoration Project Information Sharing Framework provides guidance for the types of indicators, globally, that are being collected to measure restoration effectiveness across all ecosystems (Gann et al., 2022). These indicators help not only with monitoring and assessment, but with initial project design. New data gathering and modelling approaches are emerging, from eDNA analysis that produce comprehensive species lists for biodiversity monitoring, to flux towers for 'near-live' greenhouse gas emissions monitoring and, of course, satellite monitoring of water quality parameters providing assessment of historical and contemporary responses to environmental change. New global water quality modelling products will be made available through the World Water Quality Assessment and existing maps on pressures and impacts are already available, for example through the World Resources Institute Water Risk Atlas and Aquaduct products (https://www.wri.org/aqueduct) and the UNEP World Environment Situation Room (https://wesr.unep.org/).

## Embrace both ecological and wider societal benefits

Engaging stakeholders and drawing on all types of knowledge, including that of local and indigenous communities should be a priority. To learn and understand from past successes or failures is also critical for restoration. These recommendations are included in the International Principles and Standards for the Practice of Ecological Restoration (Gann et al., 2019), which are being further adapted to guide the UN Decade 2021–2030 and which can be specifically adapted for lake and water body restoration. Following a standards-based approach to lake restoration can help reduce uncertainty and risk, thereby leading to improved restoration outcomes for people and nature. Monitoring and assessment of a wide range of sustainability indicators is already underway. In Europe, the European Commission has funded the development of new monitoring and assessment methods, transferable across ecosystem types and scales, based on the sustainability criterion of the European Green Deal (Fig. 7). This work includes awards for innovation and provides investment for restoration activities across 17 European Restoration Case Studies. The evidence and information gathering phase, prior to selection of appropriate interventions is key, and should focus on maximising gains and futureproofing interventions, particularly in light of climate change scenarios.

## Enhance national institutional capacities to accelerate scaling-up

In some countries, lake management is embedded within existing programmes and national or international policies (e.g. USA, Canada, Australia, Europe, UK, and China). As a result, capacity to respond is high, although willingness to adopt new frameworks may still be limited. In others, lake management programmes are in their infancy or do not yet exist, meaning that willingness to adopt new frameworks may be high whilst the capacity to implement them is low. There are many international directives and transboundary Strategic Action Plans that are at various stages of development. This field is rich in evidence and experience, and knowledge exchange should be prioritised to accelerate coordination and uptake.

## Foster synergies between ecosystem restoration and climate change adaptation

The role of natural infrastructure as a subset of Nature-based Solutions is embedded within climate change adaptation planning.

Established under the Cancun Adaptation Framework and supported by Article 7 of the Paris Agreement, the National Adaptation Planning (NAP) Process supports governments to identify major vulnerabilities to climate change and to develop strategies to address them. For example, the UK Climate Change Risk Assessment (UK CCRA3, 2022) states that "The UK government is committed to protecting the UK's terrestrial and freshwater habitats and species and so we will scale up our actions on ecosystem restoration, the establishment of Nature-based Solutions and building resilience of species and habitats to climate change." The UNEA-5 Resolution defines Nature-based Solutions as "actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits." Here, a clear opportunity exists to consider sustainable lake management within a Net Zero Plus approach whilst acknowledging that lake degradation will be accelerated by climate change, providing a broad suite of benefits to people, nature, and climate. The GEF/UNDP-UNEP NAP Global Support Programme provides support to over 45 countries in technical, institutional and financial needs to integrate climate change adaptation into national planning and financing.

## Enabling conditions are required to de-risk investment

A major concern in implementing global scale sustainable lake management is the lack of effective finance mechanisms. The role of the private sector is, therefore, essential for achieving success over decades' long programmes. Awareness raising and disclosure processes will be key to accelerating private sector uptake. For example, Nature-based Solutions and Natural Climate Solutions proposed for the private sector as a contribution to building resilience to climate change globally are highly relevant to freshwater restoration (WBCSD, 2022). Fiscal interventions and co-financing for restoration can reap significant rewards. Estimates on return on investment indicate that a USD 10 million investment in 'water fund' management could realise USD 21 million in economic benefits over 30 years (Russi et al. 2013; TNC, 2015). However, currently, there is a large short fall of finance for conservation projects, but there are increasing opportunities (Rodewald et al., 2020). These include the Coalition for Private Investment in Conservation (CPIC, 2023), the Conservation Finance Alliance (CFA, 2023), WWF Conservation funds (WWF, 2023), and the Landscape Finance Lab (Landscape Finance Lab, n.d.). There will be many opportunities for Nature-based Solutions for water management (WWDR, 2018) that can also alleviate poverty through green economies, including Conservation Agriculture and Agroforestry (FAO, 2014) and nature-positive agricultural subsidies (Moran et al., 2021). Experience should be shared from emerging initiatives on green finance. For example, the EU Biodiversity Strategy and the EU Nature Law will further accelerate new funding opportunities for freshwater restoration (e.g. Fig. 7). Payment for Ecosystem Services schemes are operational in a number of countries (Abell et al., 2019; Bennett & Carroll, 2014; Gartner et al., 2013) and international public finance is used through a variety of mechanisms for similar catchment management initiatives.


**Figure 7.** Indicators of restoration benefits relevant for lakes following the framework of the European Green Deal Goals, as developed by the EC MERLIN Project. Potential indicator descriptions and data sources in Europe are listed (adapted from: Carvalho et al., 2022).


3

# A Proposed Agenda for Action

The option of 'business as usual' merely drives further degradation of lakes, harms communities that depend on them and accelerates the loss of freshwater life. This is an unacceptable future scenario, given the dramatic impact it has on millions of people in terms of health, wellbeing and economy.

As the urgency for the protection and restoration of lakes is increasingly recognised, the United Nations Environment Assembly at its resumed fifth session in February 2022 adopted a Resolution on Sustainable Lake Management initially proposed by the Government of Indonesia.

Resolution UNEP/EA.5/Res.4 raises awareness of the need for sustainable lake management at a global scale, and one that aligns well with the ILEC principles for safeguarding and management of lakes enabled by effective Institutions, Policies, Participation, Technology and Innovation, Information and Finance (see Box 3, Fig. 5). Similar calls have been made elsewhere (Darwall et al., 2018; Tickner et al., 2020), and within the mandates of, for example, the Ramsar Convention, the Convention on Biological Diversity, the World Heritage Convention and the aspirations of the SDGs.

Existing global ambitions require concerted action that can embrace all tiers of governance from that affecting an individual lake and its catchment to better implementation of globally supported policies. The international frameworks (e.g. Ramsar Convention, CBD, SDGs), and mechanisms that can guide international finance (e.g. GEF, World Bank) exist. The establishment of the WWQA can provide a global communications mechanism to connect governments and stakeholders working in partnership with informed and influential global actors (e.g. UNEP, FAO, IPCC, IPBES). This provides the opportunity to connect a vast and diverse network that can effect change. UNEA Resolution UNEP/EA.5/Res.4 on Sustainable Lake Management provides an impetus for greater international mobilisation to accelerate such change.

**Left.** Harmful algal blooms float towards the coastline of Lake Erie, US, in 2017. Photo Credit: Aerial Associates Photography, Inc. by Zachary Haslick.

## Box 5. UNEA Resolution on Sustainable Lake Management

Resolution UNEP/EA.5/Res.4, was adopted by the United Nations Environment Assembly on 2 March 2022. It is a rallying cry for the world's governments to accelerate the sustainable management of lakes within the framework of the United Nations 2030 Agenda for Sustainable Development.

The resolution, calls on all Member States and specialised agencies to undertake and implement the following:

a. To protect, conserve, restore and ensure the sustainable use of lakes through integrated management as set out in targets 6.5 and 6.6 of the Sustainable Development Goals;

b. To integrate lakes into national and regional development plans, including in climate adaptation, water resource management and conservation of biodiversity;

c. To take into account their local culture and knowledge and their dependence and impact on lakes, ensuring engagement with and capacity-building for local communities and indigenous peoples;

d. To involve all stakeholders, including university and research centres, private companies and non-governmental organisations, in a concerted effort to implement sustainable lake management;

e. To take into account research and scientific guidance, with an emphasis on science-policy linkage;

f. To develop international networking and collaboration for integrated sustainable and climate-resilient lake management and regularly exchange data and information between States that share a transboundary lake.

The resolution calls on the Executive Director of the United Nations Environment Programme to support the implementation of the resolution following three major areas:

a. To support the advancement of sustainable lake management at all levels, in coordination with relevant conventions;

b. To facilitate collaboration among Member States and members of specialised agencies in research, capacity-building and the sharing of knowledge, information and best practices, including through North-South, South-South and triangular cooperation;

c. To advance the mainstreaming of sustainable lake management in the global agenda and raise awareness of sustainable lake management at the global level to further highlight the important role played by lakes in supporting sustainable development and maintaining the well-being of ecosystems and humanity.

# Four Key Actions to Build Global Capacity

This White Paper calls for an ambitious programme of international action to address the challenges as outlined in the earlier sections, especially those raised by the Global Community of Practice. Building on the UNEA Resolution on 'Sustainable Lake Management' (UNEP/EA.5/Res.4; Box 5), we propose Four Key Actions for consideration by all countries.

## 1. Build Capacity in Monitoring and Assessment

Monitoring to guide management is key, but often restricted through limited resources and capacity. We advocate for approaches that:

### Improve global coverage of long-term lake monitoring networks

Established long-term monitoring stations on lakes and reservoirs have historically acted as sentinels of environmental change, so called 'canaries in the coal mine'. They provide early warning on the impacts of contemporary and emerging pressures essential for informing international responses. Yet, funding for coordinated and harmonised long-term monitoring is highly variable at national scales. A coordinated global initiative focused on building an international network of long-term lake monitoring sites, including ecosystems from all countries, will allow the recognition of regional trends in water quality and the drivers and pressures that can cause them as well as restoration effectiveness. For example, the expansion of the Global Lake Ecological Observatory Network (GLEON) could be considered, especially for the Global South. This provides for long-term monitoring and national or regional demonstration sites, knowledge exchange and innovation, and knowledge exchange across countries.

### Accelerate integrated open-data sharing

Freely available remote sensing and *in situ* data should be harnessed to assess changes in extent and surface water quality of lakes and reservoirs, globally. For reservoirs, a large volume of data on water quality and use (e.g. for drinking water) is currently restricted on the grounds of commercial sensitivity. These restrictions on accessing data should be addressed. Data gathered remotely or through i*n situ* monitoring should be made available to the international community to foster communication on lake quality status and enhance engagement. Data hubs exist (e.g. World Resources Institute Aquaduct, UNEP World Environment Situation Room, World Bank Water Data, UNESCO World Water Quality Portal, and the European Space Agency Global Earth Observation System, UN SDG 6 Data Portal) yet no dedicated platform exists for lakes – this should be addressed. Care should be taken to avoid duplication of effort across hubs and to ensure that data products, future scenarios, and maps display outputs that are of high value (and quality assured) to relevant institutions within countries, for example, in informing national monitoring and assessment programmes and adaptation planning.

### Support national monitoring and assessment programmes

SDG 6 has the potential to enhance national monitoring and assessment of water quality and biological health of lakes. As SDG 6 implementation enters its third phase (2023-2026), the challenge is to support countries to collect the prerequisite data whilst also increasing the use of these data to generate information for policy and investment decisions. Data and information are essential for delivering water quality improvement (SDG target 6.3) as well as freshwater ecosystem protection and restoration (SDG target 6.6). Enhancing national capacity can be achieved through the SDG Global Accelerator Framework including Data & Information, Financing, Capacity Development, Innovation, and Governance to help countries improve national scale monitoring and assessment and to establish restoration programmes. Stimulating and implementing smart monitoring networks using citizen science and novel surveillance tools (e.g. sensors, video tracking, drones, remote sensing) can aid in data generation.

## 2. Embed Sustainable Lake Management within National Policy

Many countries and (in the case of the EU) regions have developed and continue to learn from long-term catchment management planning, reporting from monitoring and adapting from experiences. Models for both initial planning and adaptive planning cycles are well established, but often not applied effectively. We, therefore, promote actions to:

### Develop National Lake Recovery Plans

Countries should consider the status of their lakes within national inventories, identifying recovery plans at national and priority catchment scale. These assessments could follow the Integrated Lake Basin Management Framework including wider sustainability indicators and time bound targets, mitigation and adaptation plans, and commitments to financing. National targets should map onto the ambitions of existing international frameworks.

The CBD Target 2 sets out timelines and ambitions in this respect, although national and regional scale ambitions may already go further, and this is encouraged. Guidance on selection of adaptation and mitigation measures exists, although capacity development may be required in recovery planning, especially for those countries where lake management is not 'mainstream'. For example, innovations in sustainable lake management (e.g. through nutrient pollution reduction) targeting methane emissions reduction and enhanced carbon burial will likely become available within the next decade. At the national scale, an opportunity exists to integrate National Recovery Plans across existing policy frameworks, including Integrated Water Basin Management, Climate Change National Adaptation Planning, Conservation and Protected Areas Plans, and COVID Recovery Plans.

### Establish an International Centre for Innovation and Knowledge Exchange for Sustainable Lake Management

One of the key barriers in effective restoration identified in the WWQA Ecosystem Global Survey of Lake Restoration Practitioners is poor stakeholder engagement. Establishing an International Centre for Innovation and Knowledge Exchange will be critical in addressing this issue. The co-development of sustainable lake management plans is key, given the wide range of actors that must be engaged to deliver success. The inclusion of citizen groups in water quality monitoring is well established (Carlson, 1977; San Llorente Capdevila et al., 2020). Indeed, the WWQA works to foster Citizen's Science Initiatives through a dedicated Workstream, demonstrating the important role Citizen's Science Initiatives play in informing decision making on land-use planning and ecosystem management. Similarly, drawing on the expertise of industry experts (e.g. International Fertiliser Association, International Water Association; World Aquaculture Society; International Council on Mining and Metals) will aid to produce best practice guidance for on-the-ground change.

There is an opportunity to build on the growing social awareness and engagement in lake and reservoir management programmes across the world to inform future recovery plans and policies. Solutions to overcoming barriers in one country may inform similar responses in another. This will be particularly important for transboundary ecosystems, or lake districts, but should also consider opportunities for partnership policies targeting networks of smaller waterbodies; investment should be viewed from a benefits perspective. The International Centre should work to support countries in co-developing actions with local NGOs and governments focusing on restoration activities, providing verification of their scientific soundness and risk.

## 3. Foster Green Finance Partnerships

Finance for nature approaches have seen much innovation in recent years. This includes investment vehicles to fund business models that increase environmental resilience and, of course, leading to reduced greenhouse gas emissions. Drawing on the experience of established initiatives, and recognising the inherent links between lakes, their catchments, ecosystems and communities, we recommend to:

### Establish a Global Green Finance Fund for Lakes

We call for the creation of a global blended funding model to support the implementation of lake protection and restoration. We highlight here the urgent need for finance to help communities respond to ecosystem degradation, especially in developing economies. Lessons could be learned from other such initiatives. For example, the Global Fund for Coral Reefs (GFCR) is a 10-year USD 625 million blended finance mechanism, catalysing USD 2-3 billion from global public and private institutions. The GFCR creates a shared investment plan through which investible projects can be funded through 'Grant Funding' (i.e. from member states and philanthropies) whilst providing investment capital and introducing new investors to scale initiatives and maximise impact of grant funded projects, through an investment fund. The GFCR was co-founded by a coalition of bodies including UNEP, the Prince Albert II of Monaco Foundation, the Nature Conservancy and the UN Capital Development Fund and has grown to include more than 40 partners in its coalition. We propose a similar model for lakes (Fig. 8).

For lakes, examples of estimates of scale of return on investment for contemporary case studies include Lake Toba, Indonesia, where ecological impacts and increasing human health risk associated with harmful algal blooms have been driven since the 1990s by increasing nutrient pollution, associated largely with aquaculture, livestock and wastewater sectors (World Bank Group, 2018). 'Future world' scenarios have been developed for Lake Toba to demonstrate the potential benefits of transitioning away from existing unsustainable practices towards ecotourism. For Lake Toba, eco-tourism benefits may include more than 3.3 million visitors by 2041 (including 265,000 foreign visitors; total income USD 162 million) creating 5,000 additional jobs. A similar approach has been taken in addressing nutrient pollution and the impacts of algal blooms in Lake Villarrica, of the Chilean Lake District. Here an investment of USD 104 million over a 15 year period is projected to return social and economic benefits in the order of USD 1.8 billion (https://www.bcn.cl/leychile/navegar?idNorma=1121466). These estimates do not include global societal costs of reducing methane emissions from lakes and their catchments.

For lakes, just as for coral reefs, Nature-based Solutions are revenue-generating

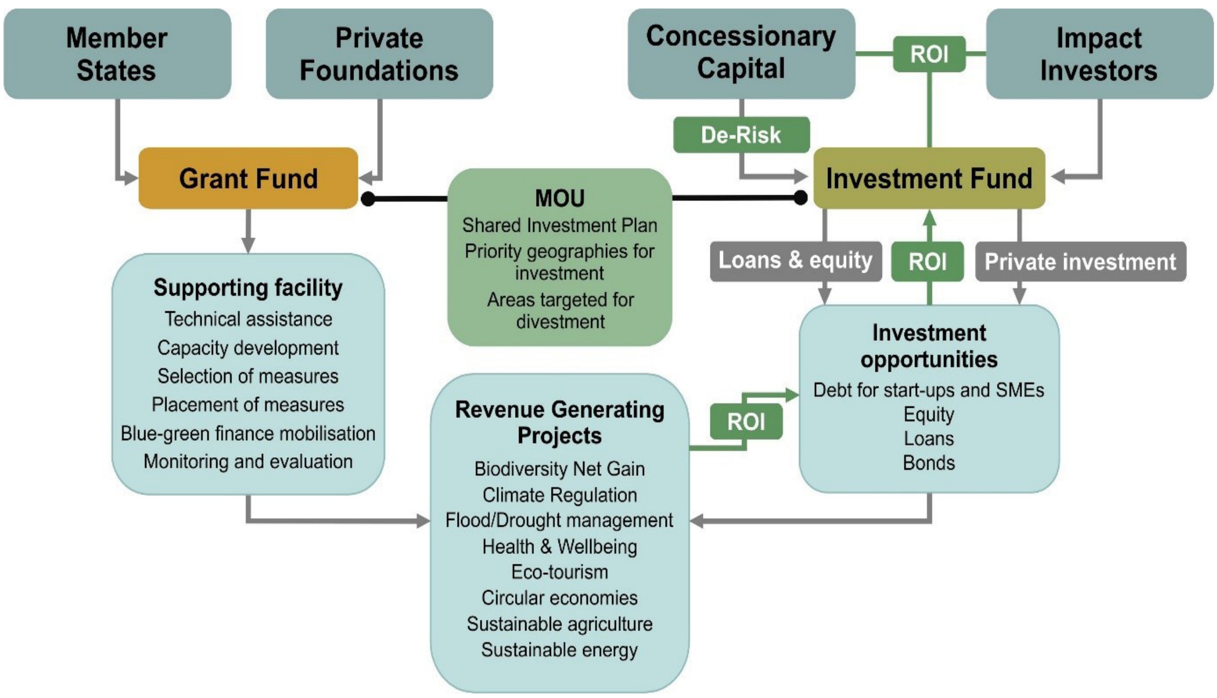


**Figure 8.** A hypothetical Blended Finance Model for Lakes following the framework of the Global Fund for Coral Reef Coalition. ROI – Return on Investment. Source: Global Funds for Coral Reefs (globalfundcoralreefs.org).

interventions. They will deliver protection and restoration of ecosystems whilst transforming livelihoods. They will build resilience in communities reliant on degraded ecosystems. The first task will be to assess the landscape of revenue generation opportunities and to form the Coalition. The majority of the case studies reported on in the Global Survey were investing in interventions that delivered revenue through eco-tourism, although the scope of monetising benefits across the full value chain needs quantifying (e.g. Fig. 7).

### Increase national funding for capacity development in disaster response

There is an urgent need to secure national funding for capacity development to strengthen institutional responses at local level in disasters response. Here, disasters may include disruption to drinking water supplies, human exposure to contaminated water, mass animal mortalities, and loss of income due to collapse of essential businesses (e.g. eco-tourism or aquaculture). This is especially relevant in the Global South where support is needed for dedicated local projects being carried out by regulatory bodies and NGOs. The central objective should be to prioritise resource allocation towards programmes involving Nature-based Solutions oriented towards security of water quality and quantity, building resilience to potential disasters and aiding disaster recovery where degradation has already occurred. Support will be needed in delivering capacity development and this will require mobilisation of dedicated and experienced partners (e.g. the Society of Ecological Restoration, GEMS/Water, ILEC, WWQA Capacity Development Consortium, and, others) to accelerate the uptake of best practice.

## 4. Raise Global Awareness on the Benefits of Change

A key element for moving the global agenda for lake restoration is effective outreach and communication at local, national and international scales. This necessitates a planned and coherent process. We advocate to:

### Implement a global communication campaign

Where communities are faced with exposure to contaminated water or harmful algal blooms and mass animal mortalities, awareness on the need for sustainable lake management is high. The consequences of pollution can result in public unrest. At national to global scales, our perspective is that conservation and/or protection of lakes do not typically command policy makers' attention. To address this, we call for a coordinated approach to communication targeting multiple global audiences (e.g. policy communities, companies, youth groups, NGOs, indigenous peoples' groups, philanthropic initiatives, education centres).

Policy makers benefit from clear information on the benefits of sustainable lake management, including policy options that deliver across the arena. There is a need for a continual feed of information targeting key policy events including meetings of the United Nations Environment Assembly, relevant Conferences of the Parties (e.g. Climate Change & Biodiversity), and key events and conferences (e.g. 2023 UN Water Conference).

The public should be made aware of the causes, status, and societal impacts associated with inaction on lake degradation and provided with guidance on actions that they can take personally to relieve stress on local ecosystems. Here, we point towards examples of effective communication on other environmental issues, including on plastic pollution. 'Champions of the Cause' may enhance public awareness raising.

The role of industry in awareness raising needs clarification. Clearly, some industries have a role to play in driving a transition towards Zero Pollution (e.g. fertiliser, wastewater, mining, plastic and aquaculture sectors). However, there is an urgent need to raise awareness across companies and investment groups on Green Finance Opportunities associated both with pollution reduction but also with economic growth through effective ecosystem restoration and management.

## Establish a Global Coalition for Lakes

Coordination of global action on lake management requires clear leadership, and we propose this takes the form of a Global Coalition on Sustainable Lake Management. This could bring together existing bodies with shared scopes but currently disconnected activities to produce a coordinated mission. Active in this area are the International Society of Limnology (SIL), the World Bank and Global Environmental Facility (GEF), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the International Union for the Conservation of Nature (IUCN), the International Institute for Sustainable Development (IISD), the International Lake Environmental Committee (ILEC), the African Centre for Aquatic Research and Education (ACARE), and the Society of Ecological Restoration (SER).

The Global Community of Practice established by WWQA Ecosystems represents a valuable resource (>60 countries engaged). It has the potential to provide real-time and historical experiences gained through implementing lake and reservoir management programmes. Engagement with this community should be enhanced – they represent both a valuable knowledge resource as well as willing recipients of new knowledge and an active body through which the Green Finance Fund for Lakes can be engaged.

The bodies mentioned above, and others, each make significant contributions to the wider practitioner community. For example, SER, with input from the Food and Agriculture Organisation (FAO) and UNEP are developing updated guidance on monitoring for restoration projects through a multi-stakeholder process and furthering the International Principles and Standards for the Practice Ecological Restoration (Gann et al., 2019), as well as broader restoration guidance for applicability across the full suite of ecosystem restoration activities under the UN Decade on Ecosystem Restoration. The new initiative includes opportunities for projects to share impact stories (https://ferm.fao.org/).

The Global Coalition for Lakes should set the agenda for future priority actions, acting as a conduit between the Global Community of Practice and the international policy community, supporting the implementation and revision of relevant resolutions through engagement with the United Nations Environment Assembly process.

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# Annex 1. List of respondents to Global Survey of Lake Restoration

List of respondents to WWQA Ecosystems Global Survey of Lake Restoration Practitioners (as of November 2022). Respondents listed below is restricted to those whose data could be interpreted accurately and where permission to be acknowledged was indicated.

| Name | Organisation |
|---|---|
| Leonardo Lagomarsino | CONICET, Argentina |
| Rodrigo Sinistro | CONICET, Argentina |
| Arevik Hovsepyan | Country Water Partnership, Armenia |
| David Hamilton | Griffith University, Australia |
| Grant Douglas | CSIRO, Australia |
| Georg Wolfram | DWS Hydro-Ökologie, Austria |
| Martin Dokulil | University of Innsbruck, Research Department for Limnology, Mondsee, Austria |
| Boris Adamovich | Belarusian State University, Belarus |
| Jeroen Van Wichelen | Research Institute for Nature and Forestry (INBO), Belgium |
| Q Zhao | Namur university, Belgium |
| Luc Denys | Research Institute for Nature and Forest, Belgium |
| Erick Loayza | Instituto de Ecología, Universidad Mayor de San Andrés, Bolivia |
| Kene Dick | Department of Water & Sanitation, Botswana |
| Marcela Miranda | National Institute for Space Research (INPE), Brazil |
| Marcelo Manzi Marinho | University of Rio de Janeiro State, Brazil |
| Ryumeko Melchior | Geographic Institute of Burundi, Burundi |
| Merlin Nganso | Cameroon |
| Patricia Chow-Fraser | McMaster University, Canada |
| Rob Bowen | Swan Lake Christmas Hill Nature Sanctuary, Canada |
| Wendell Koning | Alberta Lakes Management Society, Canada |
| Amerindia Jaramillo | MMA, Chile |
| Huihuang Chen | Institute of Urban Environment, Chinese Academy of Sciences, China |
| Jun Zuo | Institute of Urban Environment, CAS, China |
| Min Yang | RCEES, China |
| Miao Xiang | Institute of hydrobiology, Chinese Academy of Sciences, China |
| Sandra Marcela Lozano | CVC, Colombia |

| Name | Organisation |
|---|---|
| Petar Žutinić | Department of Biology, Faculty of Science, University of Zagreb, Croatia |
| Jiří Peterka | Institute of Hydrobiology, Biology Centre of the Czech Academy of Sciences, Czech Republic |
| Petr Blabolil | Biology Centre CAS, Institute of Hydrobiology, Czech Republic |
| Petr Znachor | Biology Centre of Czech Academy of Sciences, Institute of Hydrobiology, Czech Republic |
| Kasper Reitzel | University of Southern Denmark, Denmark |
| Martin Søndergaard | Aarhus University, Denmark |
| Sara Egemose | University of Southern Denmark, Department of Biology, Denmark |
| Theis Kragh | SDU, Denmark |
| Jorge Celi | Universidad Regional Amazónica Ikiam, Ecuador |
| Karen Portilla | KULeuven, Ecuador |
| Alo Laas | Estonian University of Life Sciences, Estonia |
| Ingmar Ott | Estonian University of Life Sciences, Estonia |
| Külli Kangur | Estonian University of Life Sciences, Estonia |
| Mark J McCarthy | Estonian University of Life Sciences, Estonia |
| Olga Tammeorg | University of Helsinki, Estonian University of Life Sciences, Estonia, Finland |
| Birhanu Kindishih | Educational Institute (University), Ethiopia |
| Dagmawi Matewos | Arba Minch University, Ethiopia |
| Hanna Habtemariam | Addis Ababa university, Ethiopia |
| Eskinder Zinabu Belachew | DebreBerhan University, Ethiopia |
| Haileyesus Girma | Haramaya University, Ethiopia |
| Sher Singh | Water Authority of Fiji, Fiji |
| Jouko Sarvala | Department of Biology, University of Turku, Finland |
| Jukka Ruuhijärvi | Natural Resources Institute Finland, Finland |
| Kalevi Salonen | University of Helsinki, Finland |
| Laura Härkönen | Finnish Environment Institute, Finland |
| Mikko Olin | Natural Resources Institute Finland, Finland |
| Tom Jilbert | University of Helsinki, Finland |
| Christine Argillier | INRAE, France |
| Vincent Bertrin | INRAE, France |
| Elina Bakradze | National Environmental Agency, Georgia |
| Ingrid Chorus | Private consultant; retired from the German Federal Environment Agency, Germany |

| Name | Organisation |
| --- | --- |
| David Ritterbusch | Institute of Inland Fisheries Potsdam-Sacrow, Germany |
| Hans-Peter Grossart | Leibniz Institute for Freshwater Ecology and Inland Fisheries (IGB), Germany |
| Joerg Lewandowski | Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Germany |
| Karsten Rinke | Helmholtz-Centre for Environmental Research, Germany |
| Mark Gessner | Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Germany |
| Thomas Mehner | Leibniz Institute of Freshwater Ecology and Inland Fisheries, Germany |
| Tim Epe | Institut Dr. Nowak GmbH & Co. KG, Germany |
| Dimitrios Zervas | Aristotle University of Thessaloniki, Greece |
| Ifigenia Kagalou | Democritus Univ. of Thrace / Management Body of Lake Karla, Greece |
| Vasiliki Tsiaoussi | The Goulandris Natural History Museum, Greek Biotope / Wetland Centre, Greece |
| Fatima Reyes | AMSCLAE, Guatemala |
| Sharon van Tuylen | AGUALIMNO, Guatemala |
| Balázs Lukács | Centre for Ecological Research, Hungary |
| Gabor Varbiro | Centre for Ecology, Institute of Aquatic Ecology, Hungary |
| István Hatvani | ELKH CSFK, Hungary |
| Tibor Erös | Balaton Limnological Research Institute, Hungary |
| Vera Iszvánovics | MTA-BME Water Research Group, Hungary |
| Gerdur Stefansdottir | Icelandic Meteorological Office, Iceland |
| Anila P. Ajayan | CISSA, India |
| Mohd Sharjeel Sofi | University of Kashmir, India |
| Priyanka Jamwal | ATREE Bangalore, India |
| Rupesh bhomia | CIFOR, India |
| Veena Srinivasan | ATREE, India |
| Cynthia Henny | Research Center for Limnology, Indonesian Institute of Sciences, Indonesia |
| Majariana Krisanti | IPB University, Indonesia |
| Jusri Nilawati | Tadulako University, Indonesia |
| Surono Parabang | Regional Environmental Management Agency, Sout Sulawesi, Indonesia |
| Tri Retnaningsih Soeprobowati | Diponegoro University, Indonesia |
| Tri Retnaningsih Soeprobowati | Diponegoro University, Semarang, Indonesia |
| Mahdi Kolahi | University of Tabriz, Iran |

| Name | Organisation |
|---|---|
| Bryan Kennedy | Ireland |
| Elvira de Eyto | Marine Institute, Ireland |
| Joan Martin | LAWPRO, Ireland |
| Diego Copetti | Water Research Institute – National Research Council of Italy, Italy |
| Luigi Naselli-Flores | University of Palermo, Italy |
| Maria Nuutinen | Food and Agriculture Organization of the United Nations (FAO), Italy |
| Mattia Martin Azzella | La Sapienza University of Rome, Italy |
| Rossano Bolpagni | University of Parma, Italy |
| Hiroshi Yajima | Shimane University, Japan |
| Zephaniah Migeni | African Center for Aquatic Research and Education, Kenya |
| Robert Migai | Homawasco, Kenya |
| Davis Ozolins | University of Latvia, Institute of Biology, Latvia |
| Ilga Kokorite | University of Latvia, Latvia |
| Jolanta Jekabsone | Latvian Environment, Geology and Meteorology Centre, Latvia |
| Amin Shaban | National Council for Scientific Research, Lebanon |
| Madalitso Magombo Chatsika | Lilongwe University of Agriculture and Natural resources, Malawi |
| Innocent Manda | Central Water Quality Laboratory, Malawi |
| Zati Sharip | National Water Research Institute of Malaysia, Malaysia |
| Annette Janssen | Wageningen University, Netherlands |
| Guido Waajen | Water Authority Brabantse Delta, Netherlands |
| Harry Boonstra | Wetterskip Fryslân, Netherlands |
| Laura Seelen | Waterschap Brabantse Delta (regional water authority), Netherlands |
| Miquel Lurling | Wageningen University, Netherlands |
| Simon Hofstra | Waterschap Brabantse Delta, Netherlands |
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# Embedding lakes into the global sustainability agenda

**Protecting and restoring ecosystems to deliver global scale socio-economic benefits**

Freshwater biodiversity is vanishing at a rate that is faster than in all other ecosystems. The 'know how' to deliver significant water quality and ecosystem improvements through sustainable management approaches and ecosystem restoration across sectors and scales is available, with many solutions providing multiple benefits underrepresented in existing policy. In taking a multidisciplinary approach to the challenge, we can now create transition plans, from catchment to global scale, to deliver both environmental gains whilst also supporting economic development through more sustainable economies. The challenge now lies in mobilising policy makers, investment and public support for change leading to ecosystem-based choices, and supporting communities in the protection and restoration of the ecosystems on which they rely.

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