FUTURELAKES
For Nature, Climate and People

Demonstrating Successful Restoration

Synthesis of 6 Demo sites

Deliverable D4.1

Publication Date: 28 February 2026

Authors: Lilith Kramer, Renata Augustyniak-Tunowska, Sacha De Rijk, Laura H. Härkönen, Jolanta Grochowska, Ifigenia Kagalou, Najla Kamergi, Camilla Hagman, Dionissis Latinopoulos, Linda May and Laurence Carvalho.

Funded by
the European Union

Contributors: Kaisa Västilä, Kristiina Vuorio, Marko Järvinen, Antti Taskinen, Kirsi Kuoppamäki, Heikki Mäkinen, Ezra Kitson, Justyna Olszewska, Lucie Novoveska, Dimitra Petrocheilou, Michał Łopata, Renata Tandyrak, Sigrid Haande, Carina Rossebø Isdahl, Natalia Lekner

Funded by
the European Union

Technical Details

Citation for deliverable: Kramer, L., Augustyniak-Tunowska, R., De Rijk, S., Härkönen, L.H., Grochowska, J., Kagalou, I., Kamergi, N., Hagman, C., Latinopoulos, D., May, L. and Carvalho, L. (2026). Demonstrating successful restoration. Deliverable 4., FutureLakes, available at: https://futurelakes.eu/knowledge-hub/deliverables.

Project Acronym	FutureLakes
Project Title	Integrating Innovations for the Protection and Restoration of European Lakes
Project Duration	10.2024 – 09.2027

Deliverable No.	4.1
Dissemination level [1]	PU
Work Package	4
Task	4.1
Lead beneficiary	UWM
Contributing beneficiaries	Deltares, DUTH, NIVA, SYKE, UKCEH
Quality Assurance Reviewer	Bryan M. Spears (UKCEH)
Due date of deliverable	31 December 2025
Actual submission date	27 February 2026

[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary	Author
V0.1			
V0.2			
V1.0			

Summary

FutureLakes assessed how six major European lake restoration programmes perform—not only on water quality and biodiversity—but also on climate regulation and resilience, societal values and economic returns. The Demonstration Sites are Lake Vesijärvi (FI), Kartuzy Lakes (PL), Lake IJssel complex (NL), Lake Karla (GR), Loch Leven (UK), and Lake Vansjø (NO). This report aims to document the broad range of benefits and impacts delivered by the six restoration programmes, as well as the associated costs, to inform smarter investment, monitoring and upscaling of effective measures across Europe.

The FutureLakes team adapted the MERLIN systemic assessment framework to lakes and selected 11 criteria grouped into environment, climate, society and economy (WFD status, biodiversity, zero pollution, nutrient loading, climate regulation and resilience, health & wellbeing, inclusivity, recreation, costs and benefits). Common indicators were used for quantitative comparison where possible; where not, site-specific indicators and expert judgement were applied. Before–after comparisons were undertaken when timeseries allowed.

Main findings

1) Environmental outcomes: progress, but uneven and often hidden by current reporting rules

- **WFD status**: Most Demonstration Sites remain at **moderate** ecological status; some basins improved (e.g., Lake Vesijärvi basin 2; parts of the Kartuzy Lakes), while others fluctuated or declined (e.g., Lake Karla after initial recovery). The WFD's "one-out-all-out" rule often masks real improvements in individual biological and water quality parameters and masks the successes of lake restoration programmes.
- **Nutrients and phytoplankton**: Long-term declines in total phosphorus (P), total nitrogen (N) and chlorophyll *a* are evident at several sites following sewage diversion, catchment measures and in-lake actions (e.g., biomanipulation, P-inactivation), highlighting success with the main goals of restoration at most sites. Diffuse agricultural nitrogen remains the most stubborn pressure. Some systems (e.g., Loch Leven) show recent rebounds in algae consistent with climate warming and internal loading, highlighting the need for expansion and adaptation of restoration programmes.
- **Biodiversity**: Five of six sites are important for wetland birds; four are designated Natura 2000 sites. Habitat creation (e.g., Marker Wadden in the Lake IJssel complex) and water quality gains have supported documented macrophyte and fish recovery at some sites (e.g., Loch Leven, Kartuzy Lakes, Lake Karla). This strong qualitative evidence of restoration success is poorly supported by the lack of regular biodiversity monitoring over time, which prevents a more quantitative evaluation of success.

2) Climate outcomes: restoration helps regulate methane, boosts resilience

- **Methane (CH_4) regulation**: Using a Bayesian model that links chlorophyll *a* to methane (CH_4) emissions, most sites show substantial emission reductions (≈46–57%) between "before" and "after" periods. However, estimates are typically 10–14× higher than IPCC reservoir defaults, indicating current IPCC accounting, which doesn't account for water quality changes, may underestimate lake emissions and gains from lake restoration programmes. More measured data are needed to validate these modelling approaches.
- **Resilience**: Lakes are central to drought and flood management (e.g., Lake IJssel complex's active water-level control; flood-risk measures at Lake Vansjø). Combining NbS (wetlands, riparian buffers, floodplains) and targeted engineering (sluices, embankments, controlled storage) is the prevailing strategy. Controlled outflows of lakes can lead to conflicts between

Funded by
the European Union

climate and WFD policy goals. This needs greater recognition and mechanisms to ensure policy coherence.

3) Societal value: health, well-being and recreation rise with water quality and access

- Recreation & wellbeing: Lake Vesijärvi, Loch Leven, Lake Vansjø and Lake IJssel complex now support year-round, high intensity recreation (e.g., beaches reopened, multiuse trails, sport fishing, events), with Kartuzy Lakes moving from limited to emerging recreation, while Lake Karla remains restricted (agriculture and nature focus). Nature-positive access and infrastructure (paths, hides, beaches) often amplify recreational benefits, underpinned by water quality gains.
- **Inclusivity**: Multi-actor governance (e.g., Vesijärvi Foundation; Morsa Water Board at Lake Vansjø) correlates with sustained restoration efforts. Lake Karla remains more centralised but is evolving.

4) Economics: benefits typically outweigh costs, but reporting is inconsistent

- Implementation costs (indicative): Lake IJssel complex ≈ **€1.03 billion** (shoreline NbS/BfS incl. island creation, refuge area, natural foreshore creation, river connectivity); Lake Karla ≈ **€432.7 million** (wetlands, artificial islets, tourism infrastructure); Kartuzy Lakes ≈ **€13.7 million** (sediment and biomass removal, recreational infrastructure, P inactivation); Loch Leven ≈ **€11 million** (sewage upgrades); Lake Vesijärvi ≈ **€11.2 million** (sewage treatment, biomanipulation, aeration, wetlands and sedimentation ponds); Lake Vansjø ≈ **€50.2 million** (treatment facilities, sedimentation ponds, wetlands, buffer strips)
- Estimated annual benefits (orders of magnitude): Lake Vesijärvi ≈ **€1.8 billion/yr** (water quality improvement, decreased P loading, groundwater abstraction, recreational activities, fisheries); Kartuzy Lakes ≈ **€149 million/yr** (incl. P recovery, job creation); Lake Vansjø ≈ **€143.5 million/yr** (drinking water, irrigation water, recreational activities). Smaller benefits reported for Loch Leven ≈ **€8.6 million/yr** (fisheries, reduction of phosphorus, algal blooms reduction), Lake Karla ≈ **€6 million/yr** (recreational activities, job creation) and Lake IJssel complex ≈ **€4.3 million/yr** (fisheries, in-lake wind energy production). These point to a significant benefit over cost in several sites, though methods and boundaries vary.

Information gaps that limit evaluation

- **Monitoring gaps**: Sparse or inconsistent biodiversity trends (esp. non-bird taxa), lacking priority substances (PFOS, heavy metals, microplastics), nutrient load and internal loading data uneven; limited social/recreational data and metrics
- **CAPEX and OPEX** often not distinguished; cost series not harmonised to a common baseline
- **CH_4 accounting** diverges strongly between Bayesian and IPCC methods
- **WFD hazardous substance list** lacks emerging pollutants
- **Policy coherence**: One-out-all-out obscures progress; diffuse agricultural N largely remains an uncontrolled pressure; climate warming can offset nutrient reduction gains, suggesting some targets and tools are not yet climate-proof.
- **Small lakes (<50 ha)** excluded from national WFD monitoring

What policy makers can do next

1. **Make monitoring fit for purpose (EU & national)**
    - Require standardised indicator sets across lakes for nutrients (including winter:summer diagnostics for internal loading), chlorophyll, biodiversity (plants,

invertebrates, fish, birds), priority substances (PFAS, microplastics, heavy metals), and societal metrics (access, visitation, inclusivity). Include small lakes (<50 ha). Tie public funding to open data delivery.

2. **Modernise chemical and climate accounting (EU)**
    - Update WFD hazardous substances lists, add guidance on microplastics/PFAS monitoring.
    - Mandate lake appropriate CH_4 methods (with uncertainty bands), and support validation so the GHG benefits of lake restoration are fairly accounted for in national inventories.
3. **Target the stubborn pressures (EU CAP & national)**
    - Incentivise diffuse nutrient controls (nutrient budgeting, buffers, wetlands, controlled drainage)
    - align atmospheric N policies with eutrophication goals.
4. **Adopt adaptive, climate-proof restoration (basin authorities)**
    - Pair NbS (wetlands, riparian restoration, reconnection) with grey assets (water level management, embankments) and long-term maintenance; plan for warming and extremes to safeguard phytoplankton and macrophyte gains.
5. **Strengthen governance and social acceptance (regional/local)**
    - Support multi-actor lake platforms (municipalities, water boards, farmers, NGOs, utilities) with stable funding; embed access & recreation infrastructure to convert ecological recovery into durable societal benefits of health/tourism value.
6. **Require comparable economics (EU & national funders)**
    - Standardise cost reporting (CAPEX/OPEX, discounting to a common year) and benefit valuation templates; report benefit–cost ratios and distributional effects (e.g., who pays, who benefits).

With coordinated, adaptive programmes that combine NbS, targeted grey infrastructure and in-lake solutions and inclusive governance, European lakes can deliver measurable water quality and biodiversity gains, lower methane emissions, and substantial social and economic benefits. To accelerate and scale success, policy should modernise monitoring and accounting, tackle diffuse pollution, and ensure comparable, long-term societal and economic benefit reporting.

Disclaimer

Views and opinions expressed are those of the author(s) only and do not necessarily reflect those of the European Union, European Commission or UKRI. Neither the European Union nor the granting authorities can be held responsible for them.

Funded by the European Union

Table of contents

Funded by the European Union

Funded by
the European Union

Table of figures

Funded by the European Union

Table of Tables

Glossary

Biodiversity-focused Solutions (BfS): Solutions focused primarily on active biodiversity restoration, such as habitat creation.

Birds Directive (BD): environmental legislation adopted in 1979 that creates a comprehensive scheme for the conservation, management, and regulation of all naturally occurring wild bird species within the European Union.

Capital expenditures (CAPEX): The up-front investment required for planning and designing activities, permitting and compliance, implementation and construction costs needed to physically implement the restoration solutions and land acquisition costs acquired to implement the restoration solutions and costs of site preparation.

Circular Blue-economy Solutions (CBS): Actions that include recovery of resources (nutrients, biomass) in the restoration process stimulating a blue economy around restoring freshwaters.

Combined Sewerage Overflows (CSOs): overflows from (older) sewer systems that release a mixture of untreated human waste, industrial sewage, and stormwater directly into local water bodies during heavy rainfall or snowmelt.

Demonstration Site: (A group of) Lake basins (lake and catchment) in the project that are a focus in WP4 for evaluating an integrated programme of measures (NbS, CBS, BfS, policy, finance, etc.) for lake status, biodiversity, society and economy (Green Deal indicators).

Habitats Directive (HD): a European Union law adopted in 1992 aimed at ensuring biodiversity by conserving natural habitats and wild fauna/flora.

Heavily Modified Water Bodies (HMWB): Bodies of water which, as a result of physical alteration by human activity, are substantially changed in character and cannot, therefore, meet “good ecological status” (WFD)

Innovation: an innovation introduces a new technical approach, policy, or behaviour (“niche idea”) to lake management (the “mainstream” approach or market)

K€: thousands of euros

Nature-based Solutions (NbS): Actions to protect, conserve, restore, sustainably use and manage natural or modified ecosystems, which address social, economic, and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits. This UNEP definition builds on prior definitions from IUCN and the European Commission.

Operational expenditure (OPEX): The recurring annual costs to operate, maintain, and ensure the solutions continue delivering benefits over time. Typical OPEX items include operation and maintenance, monitoring & reporting, labour and management costs needed for upkeep and repair of the restored area.

Restoration: the process of assisting the recovery of a damaged or degraded ecosystem towards a target state, such as good status (WFD) or favourable condition (HD).

Stakeholder: people/groups with an influence on, or interest in, lake protection and restoration

Water Framework Directive (WFD): European Directive established in 2000 intended to protect and, where necessary, restore water bodies and to prevent deterioration. Good status means both good chemical and good ecological status.

Funded by
the European Union

1 Introduction

1.1 Background

Globally, many lakes are in poor ecological condition, characterised by widespread biodiversity loss and frequent harmful algal blooms (HABs). In Europe, only 54% of lakes achieve the Water Framework Directive (WFD) target of good ecological status. In countries such as the Netherlands, Germany and Poland, more than 60% of surface waters are classified as less than good (European Environment Agency, 2024). Such degradation undermines biodiversity, ecosystem functioning and the ecosystem services that support social and economic well-being (e.g., Janssen et al., 2020).

Restoring lake ecosystems is particularly challenging because lakes often act as sinks for pollutants from their catchments (Adrian et al., 2009). Nutrients and contaminants from wastewater, agriculture and industry can accumulate in sediments for decades, sustaining internal loading long after external pressures have been reduced (Søndergaard et al., 2003). Consequently, progress in restoration is often slow. Contributing factors include poorly targeted or insufficient measures, conflicting policy objectives (Carvalho et al., 2019), inadequate financing (Poikane et al., 2024) and long ecological response times that frequently span decades (Abell et al., 2022).

Understanding barriers, recovery lags and long-term ecological trajectories is, therefore, essential for designing restoration programmes that can be sustained over time. In this report, we analyse the restoration programmes and long-term recovery of freshwater lakes across six European Demonstration Sites. We assess physical, chemical and biological responses alongside social, economic and climate resilience benefits, and relate restoration costs to the benefits delivered.

The Demonstration Sites—located in Greece, Finland, the Netherlands, Norway, Poland and the UK (Figure 1)—showcase diverse combinations of catchment, shoreline and in-lake measures addressing issues such as eutrophication, biodiversity decline and flood risk. Although legislative frameworks, such as the WFD, shape many current restoration objectives, most programmes originated decades earlier in response to deteriorating ecological and recreational quality or concerns about water scarcity.

To help address persistent barriers to restoration, three key areas of innovation offer new opportunities for more effective lake management:

- Nature-based Solutions (NbS)
- Circular and Blue Economy Solutions (CBS)
- Biodiversity-focused Solutions (BfS)

Nature-based Solutions are increasingly promoted in European and global policy as approaches that address societal challenges—such as climate adaptation—while supporting biodiversity. Circular economy approaches, including nutrient recovery and biomass reuse, are recognised in EU strategies such as the Water Resilience Strategy for their potential to reduce pollution while generating economic value. Biodiversity-focused Solutions explicitly target habitat creation and restoration to accelerate ecological recovery and strengthen resilience—an aspect often overlooked in traditional interventions.

Despite the wide benefits of these approaches, societal outcomes such as recreation, flood protection and local economic opportunities are rarely assessed systematically. Evaluations of social and economic impacts exist only for a limited number of projects (e.g., Kowalski et al., 2023; Haande et al., 2016; May et al., 2022; Temminck et al., 2021). Yet such benefits are essential for maintaining long-term public, private and political support. Integrating environmental, social and economic goals into restoration assessments can help ensure that programmes align both with policy objectives and with local priorities (Gann et al., 2019).

Because many of these innovative restoration measures are still emerging, robust and systematic assessment frameworks are needed to evaluate their effectiveness, build trust among lake managers and communities, compare outcomes across sites and guide future investments. To date, few evaluations consider restoration programmes as integrated, catchment scale interventions. This report aims to help fill that gap by supporting learning from integrated programmes of measures, informing systematic assessment approaches and guiding the upscaling of effective lake restoration across Europe.

Figure 1: Locations of the six FutureLakes Demonstration Sites

1.2 This report

This report aims to document the broad range of benefits and impacts delivered by the six restoration programmes, as well as the associated costs, for three main purposes:

To evaluate progress toward restoration goals in each lake basin, including compliance with key European environmental policies on sustainable water use (WFD) and biodiversity protection and restoration (HD & BD). These assessments can inform adaptation of local basin management plans and support national restoration plans being developed by Member States under the NRR.

To co-create knowledge with stakeholders on the wider societal and economic impacts of the restoration programmes, including synergies and trade-offs with climate policy and key economic sectors, such as agriculture, energy, water supply and recreation/tourism.

To provide learning and support practice improvement in lake restoration, informing the upscaling of successful measures across Europe. These insights will underpin the project's final output, the FutureLakes Blueprint.

1.3 Climate change

Climate change is expected to significantly influence lake ecosystems. Rising temperatures and intensifying summer droughts increase the risk of cyanobacterial blooms (Richardson et al., 2018). Warmer conditions also alter ice phenology and oxygen dynamics (Jansen et al., 2024; Jansen et al., 2025), while changes in precipitation and runoff may disrupt local water cycles (Nile et al., 2025). These impacts are already evident in several of our Demonstration Sites. For example, Lake Vesijärvi has experienced rising surface water temperatures and shorter ice cover periods (DS-Annex a). In Lake Vansjø and in Lake Karczemne (one of the Kartuzy Lakes), extreme rainfall events have increased local flooding and associated nutrient loadings (DS-Annexes f and b).

Climate-driven increases in freshwater demand will strongly shape future lake management. For Lake Karla, the primary restoration goal is to re-establish water supply functions and subsequently improve biodiversity. Similarly, the Lake IJssel complex constitutes an important future freshwater reservoir, a role that may increasingly dominate other management objectives.

While these climate-related challenges are important, the effects of climate change on restoration outcomes—or on the current condition of the lakes—was not in the scope of this study and are not analysed in this report.

2 Methods

For a comprehensive assessment of a broad set of ecological and socio-economic indicators, we set up an evaluation framework (Figure 2). Each Demonstration Site applied this evaluation framework to their case study which resulted in six detailed individual reports (see DS-Annexes a to f). Based on these individual reports, we were then able to evaluate and synthesize the impacts of the six large European lake restoration programmes. Calculations of the external loadings (2.2.4) and the determination of costs and benefits were not based on the individual reports (2.2.11 and Annex I). Details of the methods that were used to compare the outcomes of our research can be found in the different sections of this chapter. Section 2.1 explains the FutureLakes framework for evaluation.

2.1 The monitoring and evaluation framework

The systemic monitoring and evaluation framework that was adopted within this task was based on an approach developed in the MERLIN project (Carvalho et al. 2024). The MERLIN framework was originally developed to evaluate the impact of nature-based solutions on the broad goals of the European Green Deal (EGD) (EC 2021). The focus of the MERLIN project was on rivers and wetlands.

To develop a framework for FutureLakes, the MERLIN framework was modified. First, the three main Mission Restore Ocean and Waters goals (protecting and restoring freshwater ecosystems and biodiversity, preventing and eliminating pollution, making the sustainable blue economy carbon-neutral and circular) were adapted. In addition, the FutureLakes framework includes impacts on the tourism and recreation sector. The FutureLakes approach also places greater emphasis on public engagement in lake restoration, which is considered a key Mission enabler for upscaling restoration across regions and across Europe. The modified framework evaluates impacts around 11 criteria grouped into 4 themes (Figure 2). These criteria include environmental, climate and societal elements, but also outline additional data needed to benchmark the benefits of restoration programmes versus costs. Contextual data also help us to understand not just what impacts were delivered at a site, but the potential reasons for the magnitude of success, or failure, to support further learning from restoration programmes.

Figure 2: Criteria for evaluating restoration success in FutureLakes Demonstration Sites

Each of the 11 criteria has several indicators associated with them (see Annex II) and FutureLakes Milestone report). Using this fixed set of indicators allowed us to provide a solid starting point for the evaluation of the positive and negative impacts of restoration measures.

Even though the criteria and indicators in Annex II cover a broader range of goals than most lake restoration programmes evaluate, they still represent a basic framework that typically needs supplementing. There are often additional indicators specific to individual restoration projects, that are important locally or regionally, that should come from consultation with all local stakeholders. For example, there may be local or regional biodiversity priorities that are not necessarily species of international significance listed in the EU Habitats and Bird Directives. Principle 5 in the international restoration standards (Gann et al., 2019) highlights that it is important that a final set of clear goals and indicators to be evaluated in a restoration programme is agreed after meaningful consultation with local stakeholders. Thus, after being provided with the fixed set of indicators, each Demonstration Site team discussed indicators and availability of data with their stakeholders before a final set of indicators and consistent evaluation approach was defined for each Demonstration Site. Demonstration Site leads were also asked to consider how combinations of measures were needed to contribute to the overarching restoration goals, the costs of the restoration programme and the potential for replicability of measures for implementation elsewhere.

In certain instances, there might be no, or little, data on some of the framework indicators. It should be noted that lack of available data could mean several things. It could mean that a certain criteria is not relevant, and thus no data were collected, or that the criteria are relevant but no data were collected because monitoring is too time-consuming, complex or too expensive.

Each Demonstration Site was asked to summarise their lake-specific restoration programme including the timing of measures taken at the catchment scale and in-lake. In addition, each Demonstration Site collated data for the selected criteria and indicators. These individual basin results are presented in a separate document which contains 6 Annexes to this main synthesis report, with each Annex dedicated to one Demonstration Site. In the present document we refer to DS-Annex a, DS-Annex b etc. The Demonstration Site Annexes form the basis for this synthesis. This document includes three additional Annexes (I, II and III) giving more details on certain subjects.

2.2 The evaluation criteria

Specific details pertaining to the synthesis of the data have been described per criterion (Table 1) in the sections below.

2.2.1 WFD

Based on the information present in the DS-Annexes (a – f) we were able to compare the WFD status, normalized ecological quality ratio (nEQR) for phytoplankton and the concentrations of total nitrogen (N), total phosphorus (P) and chlorophyll *a* (Chl *a*) between the different sites.

To compare the WFD status, we collected the official ecological and chemical status for all lakes between 2009 (the first round of River Basin Management Plans (RBMPs)) and present. According to the WFD, two values are used to assess the state of surface waters: the ecological status and the chemical status. The ecological status refers to the overall health of a water body and is based on the condition of the ecosystem. This status combines information from three different sources: 1) biological quality elements such as phytoplankton, macrophytes, invertebrates and fish, 2) quality elements for natural flow and physical features such as the shoreline modification, and 3) physico-chemical quality elements that can be influenced by human activities such as nutrients or temperature. The selection of quality elements underlying overall ecological status differs per country and per water body type and has not been reported here. However, the nEQR for phytoplankton, the chl *a* concentrations and the total N and total P concentrations that we have collected for each Demonstration Site provide insight into the previously mentioned underlying sources 1 and 3. The Chemical status is based on an additional list of priority substances and EU wide standards (Environmental Quality Standards, or EQS) have been set for these substances. If concentrations exceed the standard for a certain water body, this water body will fail to meet a good chemical status. See section 2.2.3 Zero pollution (priority substances), for more information on (a selection of) priority substances measured at the Demonstration Sites.

To compare the phytoplankton status amongst the six Demonstration Sites, we collected the normalized ecological quality ratios (nEQRs) for each basin. Exact nEQR values were available for Lake Karla, Lake Vansjø, Lake IJssel complex, and Lake Vesijärvi. To arrive at exact nEQR values (required for plotting) for Loch Leven, we transformed the available phytoplankton status classes to nEQR values as follows Bad = 0.1, Poor = 0.3, Moderate = 0.5, Good = 0.7, with each value representing the middle of that status class. To arrive at an nEQR value for the Kartuzy Lakes, we transformed the available PMPL index value (that had a range between 0 and 5) with the formula nEQR = 1 - (PMPL index value / 5).

To compare nutrient (total P and total N) concentrations and Chl *a* concentrations between the different Demonstration Sites, we calculated yearly growing seasons averages for these substances. However, the duration of growing season differed per region and in some cases, monitoring changed over time. For Loch Leven, Lake IJssel complex, Kartuzy Lakes and Lake Karla, the growing season was defined as 1 April – 30 September. For Lake Vesijärvi, the growing season was defined as 1 June – 30 September. For Lake Vansjø the growing season was defined as 1 May – 31 October, with the exception of total N before 2005. In the case of total N before 2005 the growing season was defined as 1 June – 30 September. Note that this approach means that the values in this report may differ from officially reported WFD values. Total N data was not available for Lake Karla, to still provide an estimate of total N, we have included dissolved inorganic nitrogen (DIN) concentrations for Lake Karla in the total N results. If threshold values for status class boundaries were available for total N, total P and Chl *a* these have been added as coloured backgrounds to the time series showing the concentration changes across status classes. As the Demonstration sites span lakes of different lake type and in different biogeographic region, the reported class boundary thresholds differ by site.

2.2.2 Biodiversity

For biodiversity impacts, we mainly focused on indicators relevant to EU biodiversity policy (HD and BD). This includes indicators on area under protected status, condition of priority lake habitat types and the presence and condition of priority vulnerable or threatened species. For these criteria, there was not a large amount of quantitative data. Therefore, we largely adopted a qualitative, narrative analysis of these biodiversity measures and changes observed for each lake.

2.2.3 Zero pollution: priority substances

Each Demonstration Site was asked to provide data on the following priority substances: heavy metals, microplastics, and PFOS. In the DS-Annexes a-f, just some sites were able to provide results as data were scarce and, therefore, no synthesis comparison over the six lakes could be made. Existing results were compared to EQS thresholds, showing where thresholds were exceeded.

2.2.4 Zero pollution: nutrient loading

Decreasing nutrients flows into lakes is part of the zero-pollution strategy. The analysis of nutrient loads from lake catchments is a very important component in developing lake restoration programmes. We, therefore, consider assessment of external nutrient loading as a distinct sub-chapter and apply a general model to allow comparison across sites. The data were, therefore, not derived from the DS-Annexes, albeit estimates of nutrient loading were given to some of the Demonstration Sites using country-specific modelling tools (e.g., Lake Vesijärvi, DS-Annex a and Lake IJssel complex DS-Annex c) or measured programmes (e.g. Loch Leven, DS-Annex e).

As national nutrient loading estimates could not be obtained for all the Demonstration Sites, we compared the loads of nitrogen and phosphorus using general, theoretical models (OECD models) elaborated by Vollenweider (1968, 1976). Vollenweider models were originally developed for deeper lakes, and their intention was for the prediction of nutrients and Chl *a* level in lakes in the near future. The limitation of this method has been discussed in the scientific literature (e.g. Fenocchi et al. 2025, Jones and Lee 1986, Burden et al. 1986). According to Jones and Lee (1986) and Burden et al. (1986), the main issue is that OECD models omit internal nutrient loading in lakes, as well as using total N and P instead of directly available nutrient forms (Jones and Lee 1986). At the same time, these authors recommended using OECD models for developing eutrophication management strategies for water bodies. For this reason, it was applied to all six Demonstration Sites lakes because it allows for some comparison for lakes with different morphometrical, hydrological and catchment properties. Vollenweider's models give information about the potential size of the external nutrient loading in connection to the properties of individual lakes, and an estimate of the permissible and critical loads for its specific natural conditions.

The permissible load is the external nutrient load that does not accelerate eutrophication of the lake, whilst the critical load is the limit where, once exceeded, will cause eutrophication. The comparison of external loads between various lakes is difficult to interpret without taking a lake's morphometric and hydrological data into consideration. Vollenweider's models are a relatively simple tool for such comparison.

Total P permissable and critical external loadings were assessed using the following formulae (Vollenweider 1976):

$$L_d = 10 \times q_s \times (1 + \sqrt{\tau_w}) \quad (\mathrm{mg/m^2/year})$$

$$L_n = 20 \times q_s \times (1 + \sqrt{\tau_w}) \quad (\mathrm{mg/m^2/year})$$

where:

L_d - external permissable total P loading [mg/m^2/year],

L_n - external critical total P loading [mg/m^2/year],

q_s - hydraulic loading [m/year],

$$q_s = Q_r/A$$

A - lake area

τ_w - lake water residence time,

$$\tau_w = V / Q_r = z_{ave} / q_s$$

V - lake water volume,

Q_r - outflow volume per year

Z_{ave} – mean depth of lake

Total N permissable and critical external loadings were calculated using the following formulae (Vollenweider 1968):

$$L_{dN} = 400\ z_{ave}^{\ 0.6}\ (\mathrm{mg/m^2/year})$$

$$L_{nN} = 800\ z_{ave}^{\ 0.6}\ (\mathrm{mg/m^2/year})$$

The assessment of **spatial total P and total N external loads** were assessed using the formula (Grochowska 2015):

$$I_p = A_{ag} \times W_{ag} + A_w \times W_w + A_f \times W_f + A_b \times W_b \quad \text{(kg/year)}$$

where:

I_p- total P or total N spatial external loading [kg/year],
A_{ag} – agricultural land area [ha]
W_{ag}– coefficient of the total P or total N runoff from agricultural land in the catchment area [kg/ha × year],
A_w - area of wasteland in [ha],
W_w - coefficient of the specific spatial runoff of total P or total N from wasteland {kg/ha × year],
A_f - area of forests in the catchment area [ha],
W_f- coefficient of the specific spatial runoff of total P or total N from forests in the catchment area [kg/ha × year],
A_b - area of built-up (urban) areas [ha],
W_b- coefficient of specific spatial runoff of total P or total N from built-up areas [kg/ha × year].

The assessment of **spatial nutrient loading** for Demonstration Site lakes is based on using coefficients available in the literature (Kajak 2001, Grochowska 2015). In this model, agricultural areas are the highest nitrogen exporters to water bodies (coefficient of the total P or total N runoff between 2.6 - 26.7 kg total N/ha/year). In the case of phosphorus, urban areas are the biggest sources of P export to water bodies (1.0 - 5.3 kg total P/ha/year). Among different forms of catchment land-use, forest cover is the most optimal option (exporting between 0.02-0.8 kg total P/ha/year and between 1.62- 10 kg total N/ha/year). The total nutrient load from spatial sources is dependent on the catchment slope as well.

The **atmospheric deposition** of nutrients was also taken into consideration basing on EEA data and Pan et al., (2021), and it was calculated using the formula (Grochowska 2015):

$$I_a = W_a \times A \text{ (kg/rok)}$$

where:

I_a - atmospheric total P or total N loading, entering the lake surface area [kg/year],
W_a- coefficient of the specific atmospheric deposition [kg/ha × year],
A –lake area [ha]

2.2.5 Climate regulation

Climate regulation, in this context, has been defined as the emission of greenhouse gases (in this case methane; CH_4) from lakes. It has been shown that emissions increase with higher levels of eutrophication (measured as Chl *a* concentrations). The Chl *a* data from six restoration case studies have been examined to determine whether reducing Chl *a* concentrations by restoring lakes would reduce CH_4 emissions from lakes. Changes in methane emissions over time have been estimated using a Bayesian model constructed from a global dataset of ground-based measurements and satellite-derived Chl *a* data published by DelSontro et al. (2018). The results are explored in relation to the likely impacts of a range of restoration measures implemented across the sites and the long-term average value has been compared to the CH_4 emissions estimated for each lake using the IPCC guidance value for reservoirs of 1.46 tonnes CO_2-eq/ha/year (Pelsma and Kox 2025; Net et al., 2024). It should be noted that, because the IPCC calculation does not take changes in water quality into account, it cannot be used to estimate the potential impacts of lake restoration measures implemented. The Bayesian modelling approach was developed in FutureLakes WP5 and has been applied to the Demonstration Lakes here. It should be noted that the modelling approach currently includes high levels of uncertainty that are, at least partly, generated by applying global models at an individual lake scale.

2.2.6 Climate resilience

Lakes provide ecosystem services that increase the resilience of their catchments to climate change. Based on the information in the DS-Annexes (a to f) we have focused on ecosystem services related to water quantity such as water supply, droughts and flooding. As there is insufficient comparable data for a quantitative comparison between lakes, a qualitative analysis is provided.

2.2.7 Health & well-being

Health and well-being outcomes were co-evaluated across the Demonstration Sites based on the information in the DS-Annexes (a - f). To ensure consistency, data regarding core indicators were collected. These core indicators were selected based on public health relevance, focusing on recreational activities and, if applicable, on bathing water quality (according to EU Directive 2006/7/EC concerning the management of bathing water). Then, by data filtering, the related information was extracted and organized into a comparative table. There, we have listed the recreational use of the different Demonstration Sites and if applicable, their bathing water quality, to identify how water quality improvements enhance the availability of physical health activities.

2.2.8 Inclusivity

Inclusivity metrics were developed by comparing and synthesizing qualitative lake governance data across the Demonstration Sites, based on the information reported in the DS-Annexes (a to f) and the information collected by Szulecka (2025) as part of FutureLakes' stakeholder mapping exercise (Deliverable 2.1). Data regarding core indicators were collected, focusing on inclusivity in lake management. The related information was extracted and organized into a comparative table. There, we have ranked the Demonstration Sites according to their ability to foster inclusivity, varying from very inclusive, multi-sectoral approaches to more centralised models. A colour-scale system was applied to represent the governance complexity, providing a visual gradient.

2.2.9 Recreation & Tourism

For assessing recreational impacts, based on the information in the DS-Annexes (a to f), we have collected and filtered the data regarding the recreation metrics. These metrics covered recreational intensity, the availability of nature-oriented recreation, the infrastructure available for promoting nature recreation, and the seasonality of the activities. The related information was extracted, assessed using a 3-level scale, and organized into a comparative table. Then, we compared the recreational gradient at the six Demonstration Sites. Moreover, based on the information in the DS-Annexes (a-f), tourism metrics regarding the main activities, the type of available infrastructure, the accessibility, the number of visitors and the frequency or duration of visits were also assessed. Data gathered form this overview were organized in a table to show how strategic investments multiply recreational value.

2.2.10 Costs of measures

Based on the data presented in each of the DS-Annexes, we have created an overview of the different restoration measures that were taken at each Demonstration Site and presented these in tandem with their costs.

To estimate the costs of each restoration programme, we combined site-specific data collected by demo leads (in collaboration with local stakeholders) with literature-based cost estimates at the catchment scale. The implemented solutions, and thus, their associated costs, depend on the initial degradation state of each lake and different country economic contexts. Accordingly, our aim is to perform a simple comparison of costs and monetary benefits at the individual lake scale rather than comparing implementation costs across the six lakes.

Each demo lead was asked to provide information on both capital expenditure (CAPEX) and operating expenditures (OPEX), as restoration costs generally include both. CAPEX refers to the up-front investment required for planning and design activities (engaged during the preparation of restoration programmes such as feasibility studies, training session, environmental assessments, planning and detailed design), permitting and compliance (e.g. regulatory approvals, monitoring equipment setup, etc.), implementation and construction costs needed to physically implement the restoration solutions, including green infrastructures, labour, material and equipment (Ruangpan et al. 2024; Vicarelli et al. 2024). The CAPEX also covers acquisition costs of land acquired to implement the restoration solutions and costs of site preparation. These costs are usually proxied by the opportunity costs i.e. the foregone benefits that would have been received if land use was not changed (e.g. agricultural revenues). OPEX refers to the recurring annual costs to operate, maintain, and ensure the solutions continue delivering benefits over time (Pistocchi, 2022; Qiu et al. 2021). Typical OPEX items include operation and maintenance (e.g. sediment removal, replanting), monitoring & reporting (e.g. biodiversity surveys, water quality), labour and management costs needed for upkeep and repair of the restored area. Both CAPEX and OPEX include transaction costs, referring to legal fees, communication, quality control and decision-making processes.

The reported cost data did not allow separate estimation of the CAPEX and OPEX. OPEX are long-term costs that are, in most cases, scarce or inconsistent. They depend on several variables, which may be very project or context-specific, relating thus to the design of restoration, regional variations in labour or energy costs. Accordingly, for each lake, the total implementation cost was determined by summing the costs of the measures that have been implemented, as detailed in Table I.1 in Annex I. We note that some measures were excluded from this calculation due to the absence of cost information. To ensure consistency and comparability, all historical data were systematically adjusted to a common baseline by converting them into 2025 values.

2.2.11 Benefits of restoration

Restored lakes provide a wide range of direct and indirect benefits which can be systematically assessed through economic valuation approaches. To make these benefits explicit, we employ the concept of **ecosystem services** formalized by Costanza et al. (1997) and widely disseminated through the Millennium Ecosystem Assessment (2005). Several classification frameworks exist which differ in structure and level of detail, including those of the Millennium Ecosystem Assessment (2005), TEEB (2010), and CICES classification developed in 2013 by Haines-Young and Potschin.

We apply the typology defined by the Millennium Ecosystem Assessment (2005), the following ecosystem services:

- **Provisioning services** are defined as the products obtained from ecosystems, such as water supply and food production
- **Regulating services** are the benefits obtained from the regulation of ecosystem processes, such as water purification, flood control, air quality or climate regulation
- **Cultural services** are the intangible benefits that ecosystems provide to people, including recreational opportunities, aesthetic appreciation, spiritual fulfilment and intellectual growth.

A fourth category is added in relation to **indirect benefits** generated by the restoration programmes, including job creation and increased revenues of local businesses as well as farmers. The benefits were recorded in Karla, Loch Leven and Kartuzy Lakes.

The **economic valuation** of ecosystem services depends on their type. The provisioning services identified in the demo sites include groundwater abstraction (Lake Vesijärvi), food and in-lake wind energy production (IJsselmeer), irrigation and drinking water abstraction (Lake Karla and Lake Vansjø), fisheries (in Lake Karla, Lake Vesijärvi and Loch Leven) and P reuse after recycling the removed sediment (Kartuzy Lakes). Their valuation relies **directly on the market** since they are already subject to economic exchange (Rijkswaterstaat, 2018; CBS, 2025; Grochowska et al. 2019, Thiemer et al. 2025). Accordingly, it is sufficient to observe existing prices and adjust them to estimate the real value of the resource.

However, this method quickly reveals its limitations when considering services without a clear market, such as regulating services. To overcome this obstacle, economists have developed indirect methods, which consist of estimating the value of a service based on the costs it avoids or the expenses that would be necessary to replace it. For example, the role of a lake in water purification can be measured by calculating the cost of building and maintaining a treatment plant that provides the same service. This is known as **avoided or replacement cost logic**, widely used for regulating services (de Groot et al., 2012). The valuation of water quality improvement (**Lake Vesijärvi**) and carbon sequestration (**Lake IJselmeer**) were reported in the DS-Annexes based on the work of Lehtoranta (2013) and Baren et al. (2025), respectively. The valuation of algal blooms reduction in **Loch Leven** was conducted by (May et al., 2024) using the avoided costs method. The estimated cost of a single outbreak of algal blooms is based on loss of income to the fishery, hotels, restaurants and other local businesses. The economic value of phosphorus reduction (P entering) in **Loch Leven** is based on the abatement costs at the Scottish catchment scale and was extracted from (Vinten et al. 2017).

Another approach involves observing individuals' actual behaviour to reveal the value they place on ecosystems. These methods, known as **revealed preference methods**, use data from related economic activities. They are particularly useful for valuing non-market services such as landscapes, cultural or recreational services. For example, the travel cost method estimates the recreational value of a natural site based on the expenses incurred by visitors to get there. When observing behaviour is insufficient, **declarative methods** can be used, which directly ask individuals about their willingness to pay to preserve a service or improve its condition.

The cultural services reported in the demo DS-Annexes are limited and only cover **Lake IJselmeer** and **Lake Karla**. We complement this data with other economic valuation reported by McDougall and Craig (2020) that applies a contingent valuation in **Loch Leven.** A rough estimate of recreational activities, including boating, bathing, and fishing in **Lake Vansjø** and **Kartuzy Lakes**, was conducted based on and the number of visitors, the length of the summer season and the average daily cost of these activities in the region and using results from Zienkiewicz (2016) and Cichoń (2019).

Estimating the economic outcomes is challenging due to data gaps, uncertainty, and the complexity of valuing ecological and social co-benefits. The reported economic values derive from demo-specific reports and from academic studies conducted at the Demonstration Sites. To ensure consistency and comparability, all historical data were systematically adjusted to a common baseline by converting them into 2025 values and reported in Table I.2 of Annex I.

3 Results

Although the common goal is water quality and ecological improvement, the dominant pressures and specific restoration goals vary from lake to lake. In this synthesis we have collected information from lakes in six Demonstration sites across Europe with the aim to better understand the impacts of measures, associated scales (time and space) and costs of the restoration efforts. We have evaluated the restoration programmes in terms of water quality and biodiversity, factors that are commonly taken into account when looking at the impacts of restoration efforts. In addition, we have included impacts on societal, economic and climate outcomes, factors that are less frequently considered in most restoration studies. The results are presented along the four themes of the FutureLakes evaluation framework: environmental, climate, societal and economic (Figure 2).

FutureLakes' six Demonstration Sites represent different contexts of pressures and lake restoration targets (Table 1). The lakes vary in size and their mean depth varied from 1.3 to 9.2 m. Two of the Demonstration Sites (Lake IJssel complex and Lake Karla) are Heavily Modified Water Bodies (HMWB) impacted by shoreline modifications with nature restoration goals focusing on restoring the natural functioning of habitats. The four remaining Demonstration Sites (Lake Vesijärvi, Kartuzy Lakes, Loch Leven and Lake Vansjø primarily suffer from eutrophication problems. Their main restoration targets relate to improved water quality (Table 1).

*Table 1. Demonstration Site characteristics. For additional details please refer to DS-Annexes a - f). *The maximum depth in Lake IJssel complex is due to local sandmining*

Demonstration Site	Basin name	Area (km^2)	Mean and [max] depth (m)	Direct catchment area (km^2)	Country	Goals
Lake Vesijärvi	Basin 1 and 2	107	6.8 [40]	514	Finland	Control of eutrophication
Kartuzy Lakes	Mielenko	0.078	1.3 [2]	< 1	Poland	Control of eutrophication
	Karczemne	0.404	1.97 [3]	< 1		
	Klasztorne Duze	0.137	8.1 [20]	22		
	Klastorne Male	0.575	4.8 [9]	103		
Lake IJssel complex	Lake IJssel	1130.7	4.58 [21*]	18770	The Netherlands	Flood/Drought protection Freshwater supply Biodiverse ecosystem
	Lake Marken	675.2	3.91 [31*]			

Lake Karla		34.9	2.2 [5]	434	Greece	Control of water scarcity Biodiverse ecosystem
Loch Leven		13.3	3.9 [26]	145	Scotland (UK)	Control of eutrophication
Lake Vansjø	Storefjorden	23.8	9.2 [41]	679.91	Norway	Control of Eutrophication
	Vanemfjorden	12	3.7 [17]			

3.1 Restoration measures

A vast number of external and in-lake measures have been applied at FutureLakes' Demonstration Sites, mostly prior to the enactment of WFD. In **Lake Vesijärvi**, restoration began in 1976 with the establishment of sewage treatment. Since the late 1970s, an extensive number of NbS water protection measures including sedimentation ponds, buffer zones, wetlands, a two-stage channel, green infrastructure and other stormwater management measures have been established to reduce the nutrient load to the lake. Annual biomanipulation by removal of planktivorous fish and stocking of predatory fish began in 1989 and aeration was conducted in 1979-1984 and 2007-2019. Additionally, harvesting of macrophytes has been conducted on selected shoreline areas since 2015 to prevent macrophyte overgrowth.

The restoration of **Kartuzy Lakes** has included construction of combined sewer systems, stormwater retention reservoirs and pretreatment facilities in years 2015-2017. Additionally, biomanipulation was conducted in Lake Mielenko in 2020-2022 and a sequential application of aluminium (PAX) and iron coagulants (PIX) were also introduced to the lake. Similar sequential application of coagulants were introduced to Klasztorne Małe and Klasztorne Duże in 2021-2022 where biomanipulation was also conducted in 2021-2023, and to Lake Karczemne in 2022-2023 in conjunction with biomanipulation. From Karczemne Lake, 240,000 m^3 of sediment was also removed in 2020-2023.

In **Lake IJssel** and Lake Marken, several NbS and BfS have been implemented to support restoration of fish, macrophyte, invertebrate and waterfowl populations by e.g. setting restrictions to fishing (2004; 2014), creation of nature compensation areas (2005), construction of an artificial island (Marker Wadden, 2016-2019), and construction of a fish migration river between the Wadden Sea and the Lake IJssel complex (2020).

The water levels of **Lake Karla** was restored in 2000-2006 by damming and regulating water inflows from the Pinios River to combat water scarcity in the surrounding area. In between 2007-2013, artificial wetlands were created, and native species were reintroduced to the lake. Additionally, nesting habitats for birds have been established, and reed beds and wet meadows managed during 2014-2020.

At **Loch Leven**, restoration and water protection measures were put in place between 1985 and 1997. The measures focused on reducing the external nutrient inputs from point sources by improving wastewater treatment works. In addition, in 1995, buffer strips were installed along some of the rivers that drain into the loch to reduce runoff from land entering the lake.

The restoration of **Lake Vansjø** began in 1970s with the establishment of sewage treatment. Since 2002, an extensive set of NbS measures, such as sedimentation ponds, buffer zones, grass covered water ways and flood-prone areas have been established, in addition to promoting avoidance of autumnal tillage to reduce external nutrient loading to the lake.

3.2 Environmental outcomes

3.2.1 WFD

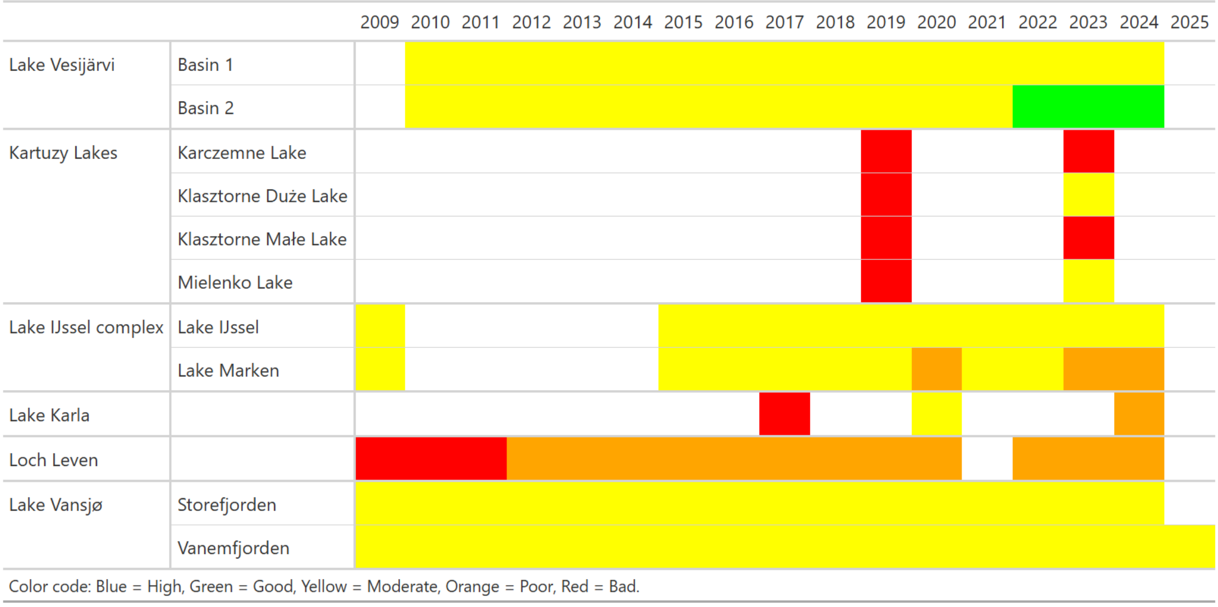
In the following sections we have grouped together the results on WFD ecological and chemical status, the information on supporting nutrient concentrations (total N and P) and more specific information on the phytoplankton quality element (Chl *a* concentrations and nEQR phytoplankton scores).

3.2.1.1 WFD status

The ecological status of the FutureLakes Demonstration Sites shows no change in status between 2009 and 2025 in 50% of the basins across the six demonstration sites, an improvement in 33% of the basins, and a worsening condition or fluctuating condition in the remaining basins (Table 2). The lakes that did not change in status have either remained in moderate status (Lake Vesijärvi basin 1, Lake IJssel and both basins of Lake Vansjø) or in a bad status (two basins from the Kartuzy Lakes). Only one basin had reached good ecological status by 2024: Lake Vesijärvi basin 2. However, it is at risk of falling back to moderate in the upcoming assessment due to the failure of one element (following the one-out-all-out principle in status assessment). Six (50%) of the basins had obtained moderate status by 2024, while three (25%) basins still have poor status and two (17%) have bad status.

The chemical status of the Demonstration Sites shows that in the latest reported year (2023/2024) six (50%) of the basins failed to achieve good status, three (25%) of the basins were in good status and three (25%) do not have information on their chemical status (Table 3). The basins that have recently achieved good status are two of the Kartuzy Lakes and Lake Karla.

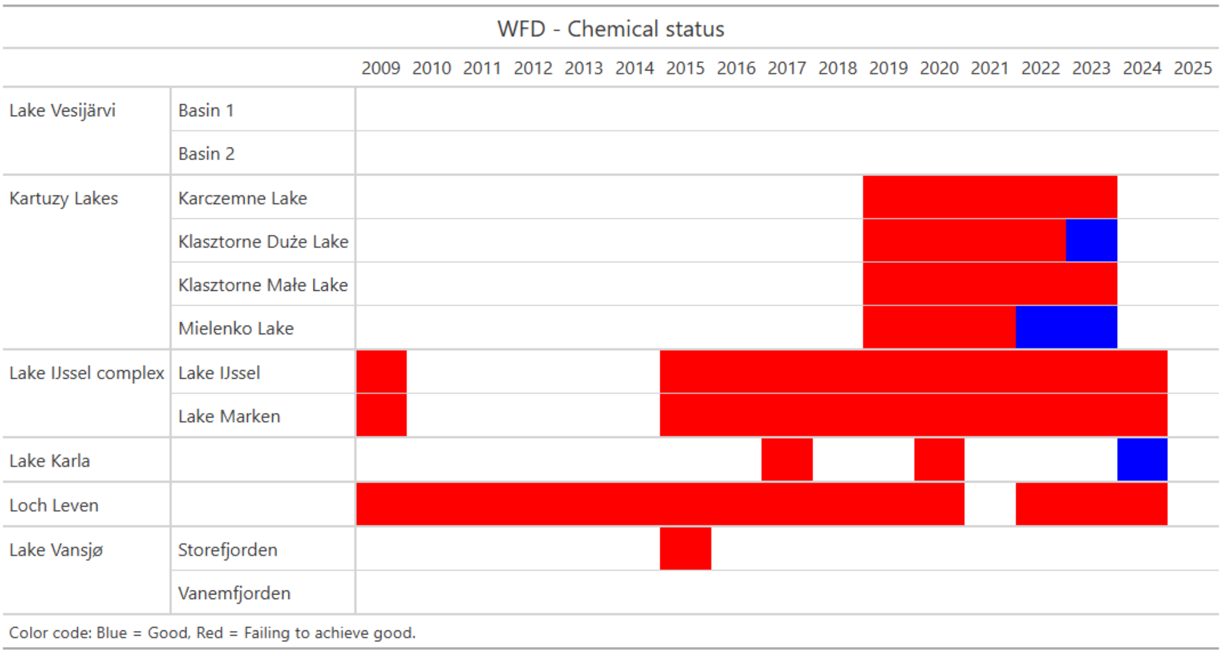
Table 2: WFD Ecological status since the first RBMPs (2009).



		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Lake Vesijärvi	Basin 1		🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
	Basin 2		🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	
Kartuzy Lakes	Karczemne Lake											🟥				🟥		
	Klasztorne Duże Lake											🟥				🟨		
	Klasztorne Małe Lake											🟥				🟥		
	Mielenko Lake											🟥				🟨		
Lake IJssel complex	Lake IJssel	🟨						🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
	Lake Marken	🟨						🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨	🟧	🟧	
Lake Karla										🟥			🟨				🟧	
Loch Leven		🟥	🟥	🟥	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧		🟧	🟧	🟧	
Lake Vansjø	Storefjorden	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
	Vanemfjorden	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨

Color code: Blue = High, Green = Good, Yellow = Moderate, Orange = Poor, Red = Bad.

Table 3: WFD Chemical status since the first RBMPs (2009).



WFD - Chemical status

		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Lake Vesijärvi	Basin 1																	
	Basin 2																	
Kartuzy Lakes	Karczemne Lake											🟥	🟥	🟥	🟥	🟥		
	Klasztorne Duże Lake											🟥	🟥	🟥	🟥	🟦		
	Klasztorne Małe Lake											🟥	🟥	🟥	🟥	🟥		
	Mielenko Lake											🟥	🟥	🟥	🟦	🟦		
Lake IJssel complex	Lake IJssel	🟥						🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
	Lake Marken	🟥						🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
Lake Karla										🟥			🟥				🟦	
Loch Leven		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		🟥	🟥	🟥	
Lake Vansjø	Storefjorden							🟥										
	Vanemfjorden																	

Color code: Blue = Good, Red = Failing to achieve good.

3.2.1.2 Nutrient concentrations

Data availability and trends for total N and total P differ per Demonstration Site (Figure 3 and Figure 4). The total P concentrations of **Lake Vesijärvi** have declined substantially since the sewage diversion in 1976, the implementation of consistent biomanipulation in 1989 and implementation of several water protection structures in the catchment area since the establishment of Vesijärvi Foundation in 2007 (Figure 3**Error! Reference source not found.**; Salonen et al. 2020, DS-Annex a). In basin 1 of Lake Vesijärvi, which was the basin most affected by domestic and industrial wastewaters during the 20th century, the total P concentrations mainly indicated moderate status since the mid-1990s and in basin 2, the total P concentrations have mainly indicated good status since the early 1990s (DS-Annex a). The median total N concentrations during the growing season in Lake Vesijärvi basins 1 and 2 have mainly indicated good and high ecological status, respectively, since the early 1990s (Figure 4). The hypolimnetic aeration, that was conducted at basin 1 between 1979-1984 and 2010-2019 had no impact on epilimnetic nutrient concentrations despite the improved hypolimnetic oxygen conditions (DS-Annex a).

The **Kartuzy Lakes** Mielenko, Karczemne, Klasztorne Małe and Klasztorne Duże have experienced marked decreases in total P concentrations after the implementation of restoration efforts in the early 2020s (Figure 3, DS-Annex b). The most pronounced decline has occurred in the most eutrophic Lake Karczemne, where both sediment removal (2020-2023) and P inactivation (2023) were conducted. Despite the decline in total P concentrations, this basin still fails to achieve concentrations supporting good ecological status. In the other Kartuzy Lake basins, that had lower initial total P concentrations, current total P levels are at levels supporting good ecological status due to P inactivation measures. The improvements in the total N concentrations of Kartuzy Lakes have caused at least two out of four basins to reach a good status (Figure 4).

At the **Lake IJssel complex** the total P concentrations have improved from levels indicating a moderate ecological status to good or high since 2010 (Figure 3, DS-Annex c), likely mainly due to measures aimed at nutrient reduction in the Rhine catchment for Lake IJssel (Frenken et al. 2023) and due to a combination of in-lake and catchment measures for Lake Marken. The total N levels, in turn, have also improved over the years. In Lake Marken these improvements have led to a good to high status since the early 2000s, while in Lake IJssel these improvements have recently led to a moderate status (Figure 4).

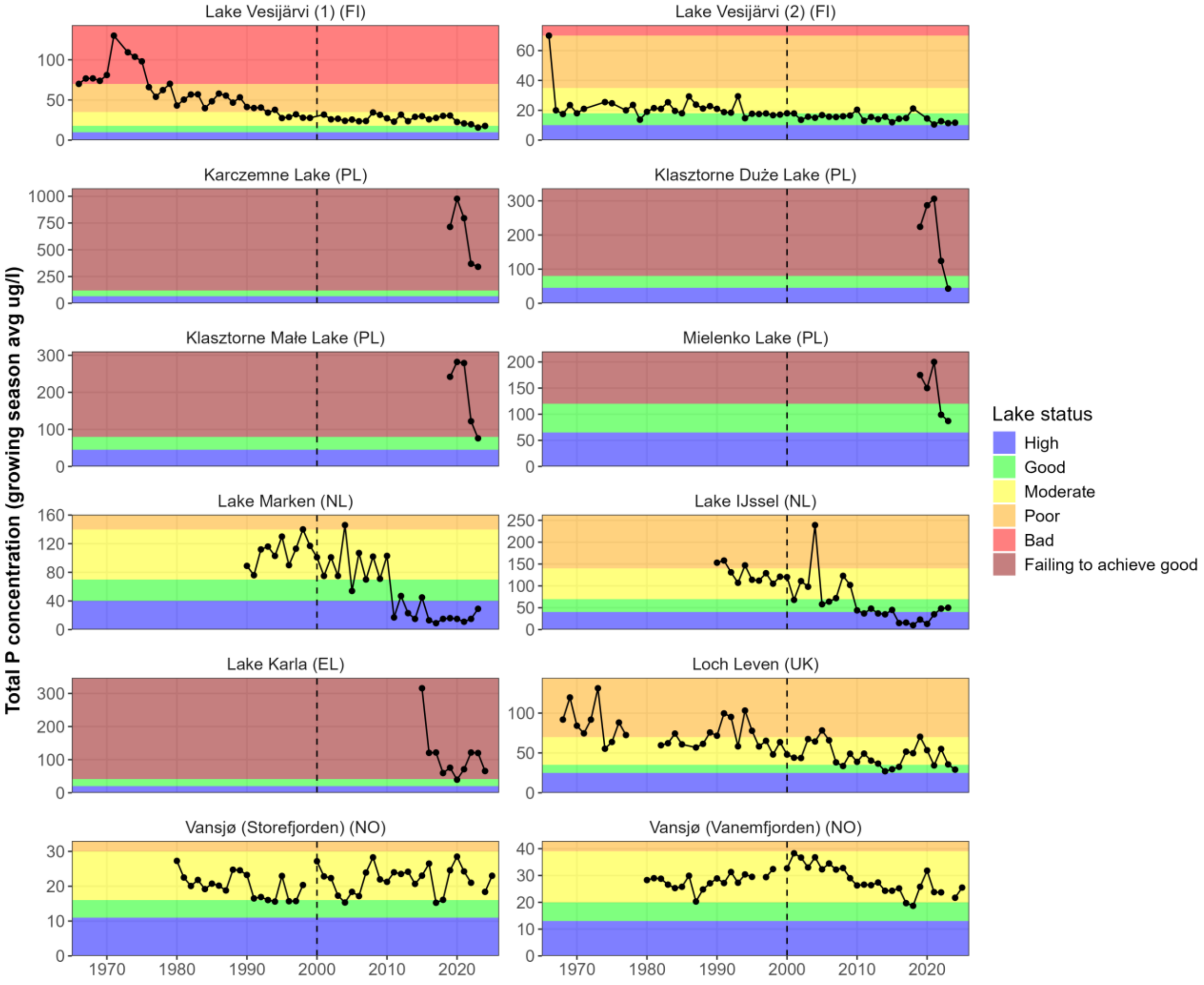


Figure 3: Average total phosphorus (P) concentrations (ug/l) across the growing season per basin. The dashed line indicates the enactment of the WFD. Note that the y-axes differ per basin. Total P values displayed here may differ from officially reported WFD values.

After the reconstruction of **Lake Karla** in 2013, the total P concentration was expectedly high, indicating a failure to achieve concentrations supporting good ecological status (Figure 3, DS-Annex d). Ever since, the total P concentration has improved and currently indicates a slightly better condition, including reaching a level supporting good ecological status once in 2020. The DIN concentration, in turn, has increased from the initial levels, currently indicating severe pressures, although thresholds for this Demonstration Site have not been defined yet (Figure 4).

In **Loch Leven**, the restoration and water protection measures were implemented mainly before the enactment of the WFD (DS-Annex e). The water quality in the lake improved over time reaching the total P targets that had been set by the mid-1990s (Figure 3). However, since 2018, the total P concentration has started to rise again and algal blooms have returned, despite inputs of total P from the catchment not changing. Recent data suggests that P release from the sediment is starting to increase again as the water temperature increases. The total N concentrations in Loch Leven fluctuated in between levels supporting moderate and good ecological status from the 2000s onwards (Figure 4).

Funded by the European Union

In **Lake Vansjø**, the total P concentration has mainly remained on a level supporting moderate ecological status in both lake basins since the 1980s (Figure 3, DS-Annex f). From these basins, the total P concentration of Storefjorden has displayed more fluctuation due to the higher susceptibility of the basin to external, climatic incidents such as landslides and flood events forcing erosion (Skarbøvik et al. 2025). In Vanemfjorden, the total P concentrations have been slightly higher since the beginning of monitoring in 1980s. Additionally, floods and years of high precipitation have caused increases in the total P concentrations in Vanemfjorden (DS-Annex f). The total N concentration in Storefjorden has fluctuated between moderate and poor ecological status, whereas in Vanemfjorden the total N concentrations have mainly displayed levels supporting good or moderate ecological status (Figure 4).

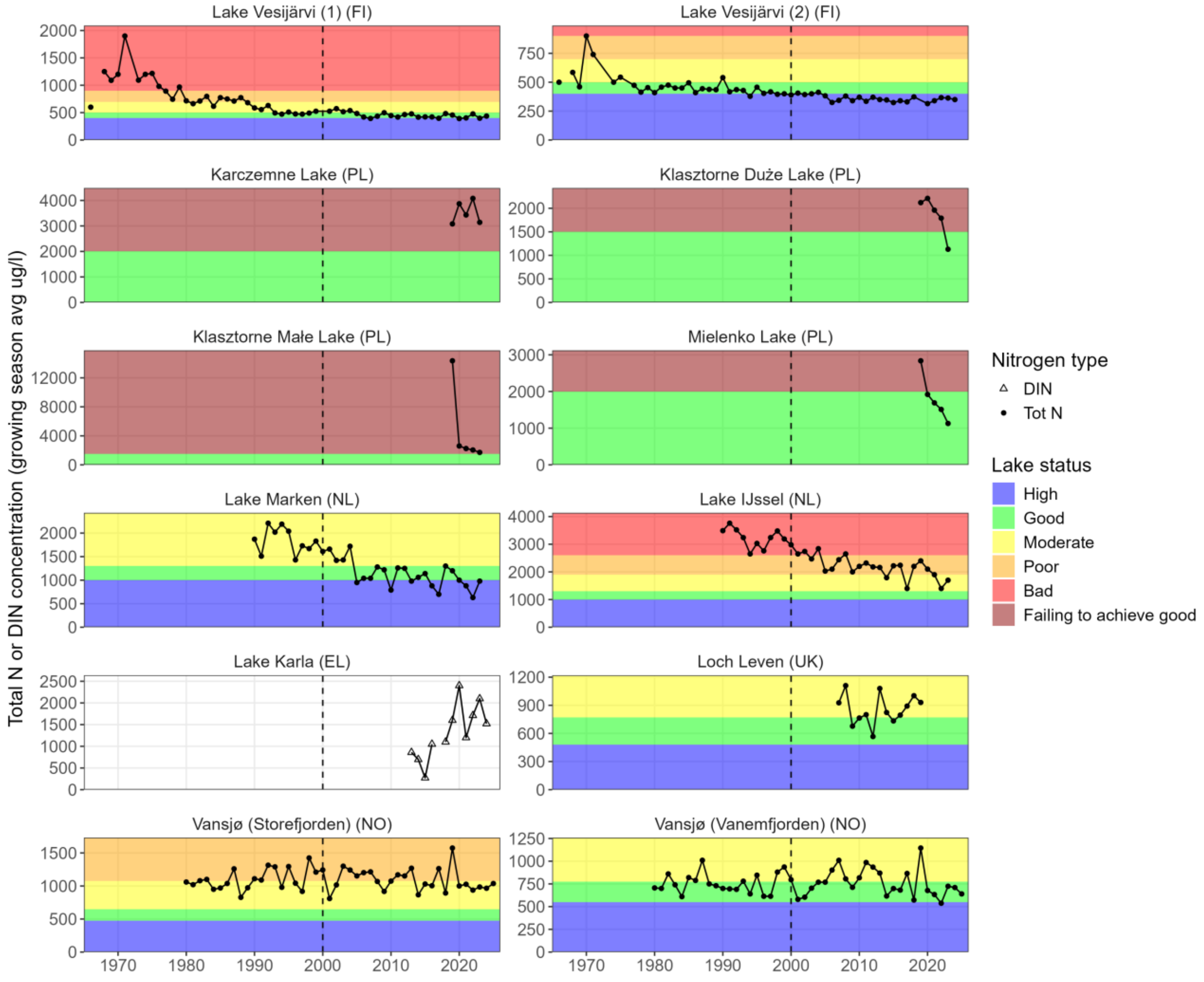


Figure 4: Total nitrogen (N) or Dissolved Inorganic Nitrogen (DIN) (in the case of Lake Karla) concentrations in ug/l in the growing season per basin. The dashed line indicates the enactment of the WFD. Please note that the y-axes differ per basin. The total N or DIN values displayed here may differ from officially reported WFD values as we prioritized comparability among the different Demonstration Sites (see methods).

3.2.1.3 Phytoplankton

Similar to nutrient levels, the Chl *a* concentration has also experienced a decline in many of the Demonstration Sites but there has also been fluctuation (Figure 5). In **Lake Vesijärvi basin 1**, Chl *a* levels first were at bad or poor ecological status but have declined to levels generally indicating moderate status after the sewage diversion in the 1970s and the onset of continuous biomanipulation (1989)

(Figure 5). Chl *a* data from **Kartuzy Lakes** are only available for five years starting in 2019 but suggest a decline since the implementation of biomanipulation and sequential application of coagulants in the early 2020s (Figure 5). Similar to changes in Total P, the Chl *a* concentration in **Loch Leven** first decreased over time but has increased again since 2018. The initial improvement of Chl *a* concentrations in the 1970s in Loch Leven was due to the fact that the inflow from pesticides into the lake from a nearby woolen mill was stopped. This reduction in pesticide pollution subsequently allowed for the return of phytoplankton-grazing Daphnids. Nutrient reduction efforts in this lake started later, in the late 1980s. In **Lake Vansjø**, the Chl *a* levels have fluctuated between levels indicating high to moderate status (Storefjorden) and poor to good status (Vanemfjorden) with highest concentrations recorded in the early 2000s. Continued inputs of P due to increased precipitation, storm events and warmer winters counteract with nutrient reduction measures. Nonetheless, after the impact of a big flood in 2000 finally dissipated around 2008, Chl *a* levels have started to decline again.

In the **Lake IJssel complex**, Chl *a* concentrations display decreasing trends since the enactment of WFD with current levels indicating good ecological status in Lake Marken and moderate status in Lake IJssel (Figure 5). However, longer time series (DS-Annex c) indicate that the decrease in Chl *a* started in the 1980s, due to nutrient reductions measures taken in-lake and in the catchment when nutrient reduction was still an important goal for these basins. In **Lake Karla**, where the primary restoration goal was to combat water scarcity, the Chl *a* levels after the reconstruction of the lake have somewhat increased.

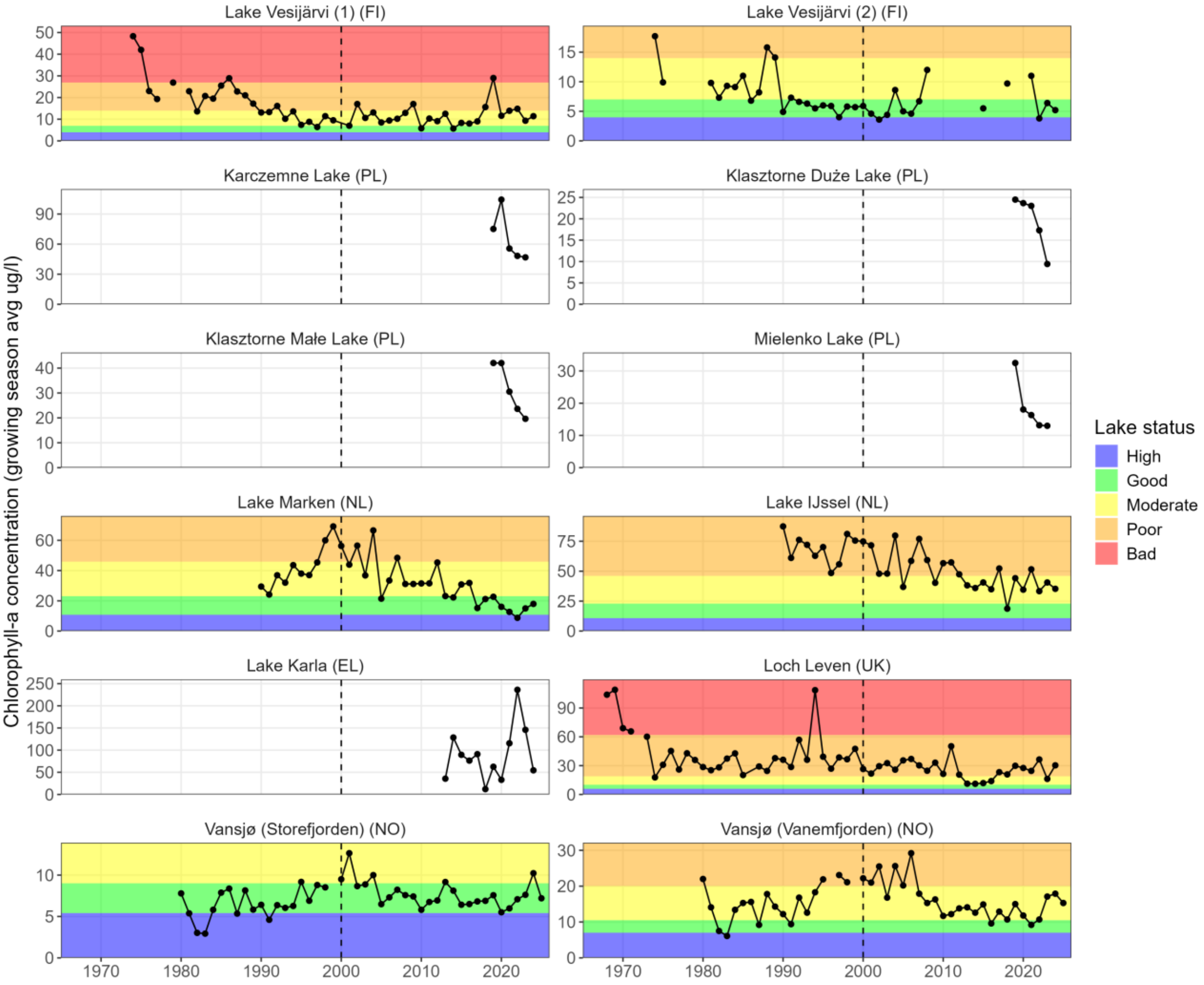


Figure 5: Chlorophyll a concentrations (ug/l) in the growing season per basin. The dashed line indicates the enactment of the WFD. Please note that the y-axes differ per basin. The Chl-a values displayed here

may differ from officially reported WFD values as we prioritized the comparability among different Demonstration Sites (see methods)

The phytoplankton nEQR of most Demonstration Sites appears to have been improved since the beginning of monitoring (Figure 6). In **Lake Vesijärvi basin 1**, the phytoplankton nEQR has mainly indicated good to moderate ecological status since the sewage diversion and the onset of biomanipulation in 1989. Although the sewage diversion in 1976 reduced the Total P concentration in Vesijärvi 1 epilimnion by circa 40%, the cyanobacterial blooms were still frequent in the early 1980s (Salonen et al. 2023). Consistent biomanipulation since 1989 has further reduced the Total P and improved the structure of the food web, consequently reducing the prevalence of harmful algal blooms (Horppila et al. 1998; Salonen et al. 2020; Salonen et al. 2023). In most **Kartuzy Lakes** and **Loch Leven**, the phytoplankton nEQR has substantially improved after the reduction of external and internal loading. Also in **Lake Marken**, the phytoplankton nEQR has improved since the active restoration measures have taken place while in **Lake IJssel** the nEQR has remained on levels indicating poor to moderate ecological status. With the increment of **Lake Karla**’s Chl *a* concentration after the lake’s reconstruction (Figure 5), the phytoplankton nEQR has also gotten worse over the years (Figure 6). At **Lake Vansjø**, where no clear trend in nutrient concentrations can be observed over the years (Figure 3, Figure 4), the phytoplankton nEQR seems to have declined during the 2000s.

Funded by
the European Union

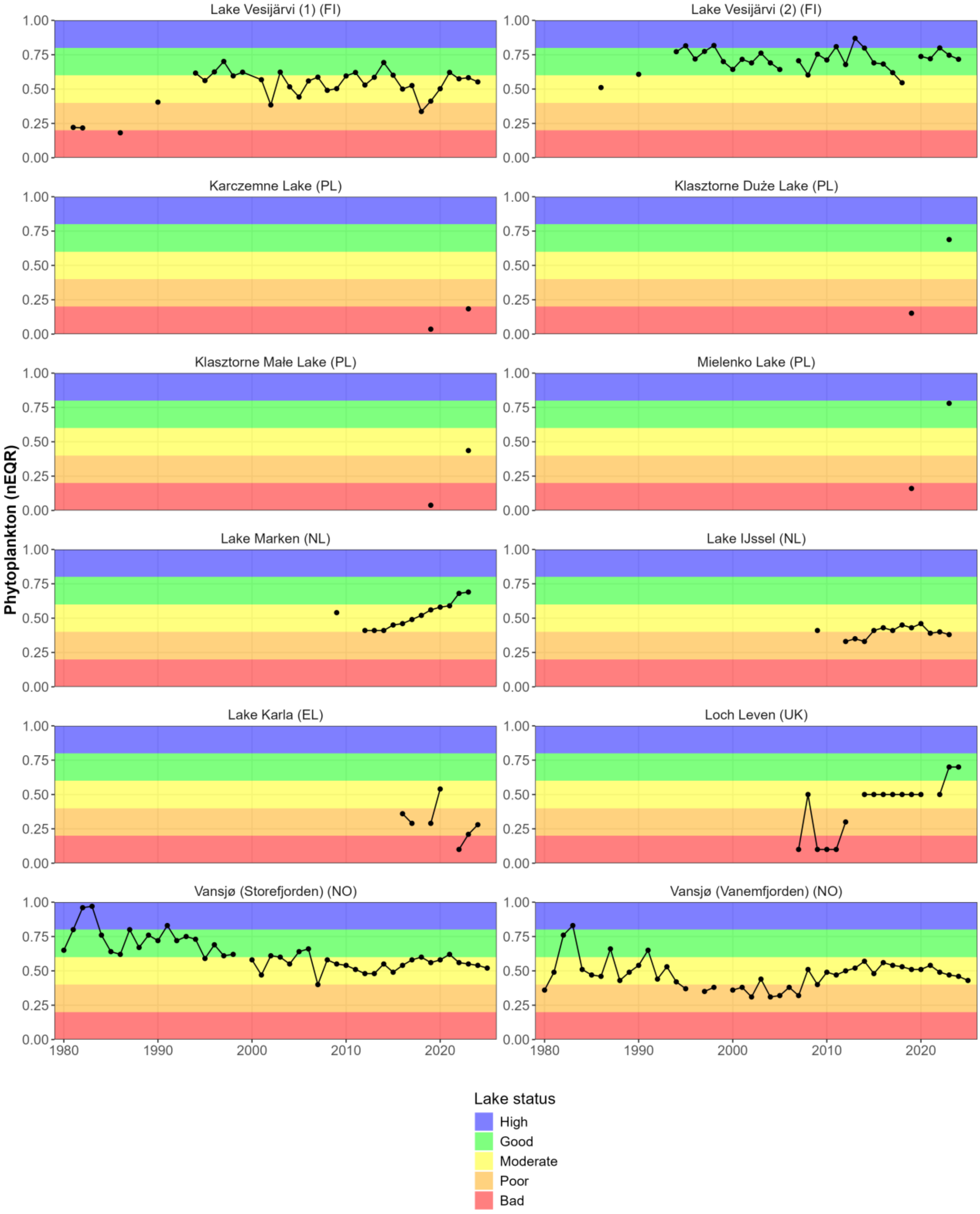


Figure 6: Phytoplankton nEQR scores of FutureLakes Demonstration Sites.

3.2.2 Biodiversity

In this section, we report on the impact of the restoration programmes of the Demonstration Sites on biodiversity goals as set out in European policies. Table 4 summarises the area of protection under the two directives and the specific habitat or species features that they were designated for. Five of the six sites are particularly important for wetland bird populations, with 4 of these designated as Natura 2000 sites under the Birds Directive. Lake Vansjø is not designated as Norway has not implemented the Habitats and Birds Directives. Of the 4 sites designated, 100% of the lake area is protected for 3 sites, whereas only 6% is protected for Lake Vesijärvi (Table 4). Only parts of the **Lake IJssel complex** and **Lake Vesijärvi** were designated for their lake habitat types (aquatic plant communities) under the Habitats Directive: with “naturally eutrophic” and high alkalinity “Hard oligo-mesotrophic” lake types notified features. **Loch Leven** and **Lake Vansjø** are not designated under the Habitats Directive but these two sites also have diverse and species rich communities of aquatic plants, characteristic of these HD high alkalinity lake types, and also include nationally red-listed plant species. The Lake IJssel complex, Lake Karla and Lake Vansjø are also recognised for their fish communities. The Lake IJssel complex is also designated for a HD priority bat species that is dependent on open surface waters for feeding on flying insects.

Table 4: The level of protection as set by European biodiversity directives: the Bird Directive (BD) and the Habitat Directive (HD).

Demonstration Site	Basin	BD area Special Protection Area (ha)	HD area Special Areas of Conservation (ha)	Reasons for designation
Lake Vesijärvi	Lake Kutajärvi and five bays at L. Vesijärvi (Kirkonselkä, Laasonpohja, Lahdenpohja, Teräväiset and Kailanpohja)	639 (6% of L. Vesijärvi)	152	30 bird species, 2 plants and 1 invertebrate. 3 habitat types (1 lake type, 2 wetland types). Ramsar site.
Kartuzy Lakes		Not designated as a Natura 2000 site		
Lake IJssel Complex	Lake Marken	68463 (100% of the lake)	1109	For two lake habitat types, 2 fish species, 1 bat and 2 breeding and 18 non-breeding birds species.
	Lake IJssel	113341 (100% of the lake)	2441	For six habitat types, 1 bat, 1 fish, 1 rodent, 1 plant and 11 breeding and 31 non-breeding bird species,

				including Vulnerable and Endangered species.
Lake Karla	Lake Karla	12,669 ha (100% of the lake)		Designated for 32 wetland bird species including the endangered Dalmatian Pelican and also 4 IUCN red-list fish species that may be dependent on water levels in streams and wetlands around Lake Karla
Loch Leven	Loch Leven	1330 (100% of the lake)	1330	A SPA (pre-Brexit) and RAMSAR site designated for 9 wintering waterbird species. Also recognised nationally for its species-rich wetland and aquatic plant communities and rare shoreline beetles.
Lake Vansjø	Vestre Vansjø nature reserve	National nature reserve. Not designated as a Natura 2000 site		Norway does not implement that Habitats or Birds Directive. Nationally it is important for its species-rich fish (21 species) and bird communities with 58 bird species and 6 aquatic plant species red-listed for Norway.
	Moskjæra nature reserve	National nature reserve. Not designated as a Natura 2000 site		

Results on the condition of species and habitats of conservation interest are summarized in Table 5. Despite their high conservation status as protected areas for birds and other species and habitats, regular monitoring and recent condition assessments were very limited for most sites, with little opportunity for any assessment of trends in biodiversity status in response to restoration programmes.

Despite this lack of quantitative evidence on the impacts of restoration measures on biodiversity, several sites document a deterioration in biodiversity, including loss of characteristic species, during the periods in each lake when there was the most severe pollution and improvements in biodiversity that coincide with improvements in water quality delivered by the restoration programmes. These qualitative trends in biodiversity are reported for each site below.

The condition of habitats (3150) and macrophyte species within the Natura 2000 areas of **Lake Vesijärvi**, based on the latest assessment in 2023, are unfavourable: declining. The condition of both is weakened by helophyte overgrowth, eutrophication and human activities. Lake Vesijärvi is among Finland's most valuable lakes for diverse aquatic flora, hosting endangered species such as watermilfoil (*Myriophyllum sibiricum*) as well as brackish water relics from its Baltic Sea past. Eutrophication in the mid-20th century altered macrophyte communities, favouring competitive species like hornwort (*Ceratophyllum* *demersum*) and common reed (*Phragmites australis*), while sensitive species such as the slender naiad (*Najas flexilis*) declined due to habitat loss from shoreline construction and small-scale dredging activities. Restoration efforts in the 1990s improved water clarity, shifting dominance toward oligo-mesotrophic species, though eutrophication-tolerant plants persisted and *N. flexilis* has not been observed. Today, the lake supports 81 recorded species, including invasive Canadian pondweed (*Elodea canadensis*), and recent surveys indicate good ecological status despite ongoing pressures from human activity. The condition of dragonflies listed in the HD Annex IV(a), in turn, is favourable: stable. Recent dragonfly surveys in Lake Vesijärvi's Natura 2000 bay areas have recorded 19 species, including lilypad whiteface and large white-faced darter (*Leucorrhinia caudalis* and *L. pectoralis*). These species thrive in fertile bays with submerged vegetation and have favourable conservation status in Finland, despite declines elsewhere in Europe. They likely benefit from improved water quality of Lake Vesijärvi, as both prefer eutrophic but not hypertrophic conditions. Additionally, the moor frog (*Rana arvalis*) is widespread in Finland and reproduces successfully in Lake Vesijärvi, particularly in Lahdenpohja bay where hundreds of individuals have been observed. The Natura 2000 areas within Lake Vesijärvi area are among the most important inland resting sites for wetland birds during aviation. However, especially the breeding waterfowl population of Lake Vesijärvi has declined remarkably since the 1970s, following eutrophication and decline of submerged vegetation, reduced shoreline grazing, invasive alien predators, hunting and increased recreational boating. While eutrophication in the 1970s supported abundant piscivorous bird species (e.g. *Podiceps cristatus*), improvements in water quality and habitat changes in the 1990s reduced the reed beds and weakened the breeding success of species like great crested grebe, coot (*Fulica atra*), and black-headed gull (*Chroicocephalus ridibundus*). More tolerant species have since become dominant, reflecting a broader national trend driven by land-use changes, invasive predators, and shifting gull colony sizes. Today, endangered species have largely disappeared from Natura 2000 areas, with black-headed gull numbers drastically reduced, though some large colonies persist on artificial islands outside Natura 2000 areas. However, *Branta leucopsis* has remarkably increased in the Lake Vesijärvi area during aviation, consistent with the national trend.

Before restoration, the **Kartuzy Lakes** were in poor condition, with sparse or absent submerged vegetation communities and massive phytoplankton blooms. After completing restoration, submerged macrophytes have been observed (*Chara* sp.). The **fish community** was dominated by cyprinid species, typical of highly eutrophic waters, and included the invasive gibel carp (*Carassius auratus gibelio*). Following biomanipulation, predatory fish were introduced (pike, zander, and asp) and excess cyprinids were harvested. These measures reduced the proportion of gibel carp and increased the presence of native predatory fish, especially in the shallow lakes Mielenko and Karczemne. In the deeper lakes, however, the predator-to-cyprinid ratio remained largely unchanged, likely due to higher angling pressure on predatory species. There are no available data on birds.

Lake IJssel complex. The latest reported conservation status of several (non-bird) species, that the lake and adjacent areas are notified for, is highly unfavourable. For example, the pond bat population has declined significantly across the Netherlands since the 1990s, but the population for the Natura 2000 site is reported to be in good condition. The bird populations with conservation designations also experienced sharp declines since the 1980s, particularly benthivorous and piscivorous species. Despite these declines, the area maintains internationally important populations of overwintering and moulting waterbirds. The building of the nature islands Marker Wadden created an increase of available habitats for several Natura 2000 species, such as common tern, avocet, ringed plover, little plover, Kentish plover, black-headed gull, little tern and sand martin. Creating new habitat for these species will almost certainly support recovery of these species and have positive impacts for EU Biodiversity and NRR policy goals.

Before drainage, **Lake Karla** harboured the most important wetlands in Greece and served as a hot-spot for biodiversity. After refilling and restoration measures, the new waterbody was given Protected Area status as a Natura 2000 site under the Habitats and Birds Directives. Nowadays, in Lake Karla, there are records of 201 and 16 bird and fish species, respectively. Among them, 50 bird species referred to in

Article 4 of EU Directive 2009/147/EC and listed in Annex II of Directive 92/43/EEC are all in good conservation status (GR1430007). Furthermore, 4 fish species referred to in Article 4 of EU Directive 2009/147/EC and listed in Annex II of Directive 92/43/EEC are present in the Lake Karla area (GR1420004). The conservation status is good for one fish species and average or reduced for the other three. In general, Lake Karla is of great importance for many breeding bird species in the area. According to the Hellenic Ornithological Society, over 200 different species of birds have been documented. The area is of particular importance for the endangered Dalmatian pelican (*Pelecanus crispus*). The first quantitative surveys of key bird species were carried out in 2024. It is, therefore, difficult to establish the precise quantitative effect of the numerous measures on (bird) biodiversity improvement due to a lack of regular monitoring data.

Loch Leven is recognized for its over-wintering waterbird species, especially internationally important populations of pink-footed geese and shoveler. It is also recognised nationally for its species-rich wetland and aquatic plant communities and a rare shoreline beetle, *Thanatophilus dispar*, a specialist feeder on dead fish or birds. Nationally, it is designated as a protected area as the largest naturally eutrophic loch in lowland Scotland with exceptional aquatic plant diversity, including stonewort species of conservation interest such as the rough and clustered stoneworts (*Chara aspera, Tolypella nidifica var. glomerata*), and nationally scarce vascular plants such as mudwort (*Limosella aquatica*) and slender-leaved pondweed (*Potamogeton filiformis*). Historical surveys dating back to 1905 reveal significant fluctuations in species richness and macrophyte growing depth over decades, with a notable decline from 16 taxa and growing depth of 4.5 m recorded in 1905 to only 7 taxa recorded in 1966 followed by a recovery in the late 1990s to mid-2010s to 13 species and growing depth over 4 m recorded in 2008. During the period of recovery, algal blooms reduced and water transparency increased. This enabled submerged macrophytes to re-establish themselves in deeper water (DS Annex e; May & Carvalho, 2010) with one species (*Potamageton praelongus*) re-appearing after an absence of almost 100 years (Dudley et. al., 2012). There is some evidence that the recovery in water quality has benefited some of the priority bird species, especially two herbivores, Coot and Pochard, reliant on macrophyte beds and two divers, Great Crested Grebe and Tufted duck which over-winter and are thought to have benefitted from longer ice-free conditions (Carss et al., 20212). All four species show stable or increasing population trends compared with declines nationally (Carss et al., 2012). In addition, pollution intolerant benthic invertebrate species also became more abundant along a similar timeline (Gunn et al., 2012). Latest surveys confirmed that Loch Leven maintains a favourable conservation status under the EU Habitats Directive.

Lake Vansjø is one of the most species-rich lakes in Norway when it comes to fish, with 21 identified species, of which 11 are native. Lake Vansjø is one of the few locations in Norway where Pikeperch/Zander (*Sander lucioperca*) is native. According to the Norwegian Biodiversity Information Centre (Artsdatabanken) and their database Artsobservasjoner.no, where volunteers can register observations, several species on the Norwegian red list were found in and around Lake Vansjø from 2000 to 2025. Moor frog (*Rana arvalis*) and European crayfish (*Astacus astacus*) are also registered. Several invasive species are also registered in and around Lake Vansjø, mainly terrestrial, e.g. the predatory mammal, mink (*Neovison vison*). Due to strict regulations on activities in the nature reserves, such as Vestre Vansjø and Moskjæra, scientists have not been able to enter the protected areas in order to make any evaluation of the breeding success for nesting birds, and the current productivity in the nature reserves are, therefore, more or less unknown. Some recent monitoring using drones has, however, indicated that Moskjæra is less attractive to birds than expected, with very few breeding pairs of some previously abundant species. Numerous professional and non-professional volunteers have frequently recorded bird life in and around Lake Vansjø, and these observations are available from the Norwegian Biodiversity Information Centre (Artsobservasjoner.no). A total of 206 species were recorded between 2000 and 2025, of which 58 are red listed according to the Norwegian red list for birds (Stokke et al. 2021) and three are regarded as invasive species.

Table 5. Summary of present status of bird and non-bird species and an expert judgement on the impact of restoration on the biodiversity of the six Demonstration Sites.

Demonstration Site	Non-bird species	Birds	Impact of restoration on biodiversity
Lake Vesijärvi	Favourable conditions for dragon flies and moor frog. Hosting endangered littoral vegetation, unfavourable condition for flora	The waterfowl population has declined significantly since the 1970s.	Reduction of eutrophication has increased the water clarity with subsequent implications for the littoral vegetation. However, piscivorous waterfowl have declined due to removal of planktivorous fish.
Kartuzy Lakes	Recently new spots of submerged macrophytes and improvement of native fish species	No data available.	Reduction of algal blooms has led to positive effects on submerged vegetation and biomanipulation has been positive for native fish species in the shallower lakes
Lake IJssel complex	Three of the five designated species have a highly unfavourable status for the Netherlands, including the Bullhead fish and the pond bat. The spined loach fish is stable.	Bird populations with conservation objectives have experienced sharp declines since the 1980s. Despite these declines, the area remains internationally important for overwintering and moulting waterbirds	Building the nature island created increased bird habitat. A number of bird species are using this new habitat and are contributing to improved Natura 2000 status and BD and NRR goals. The condition of the non-bird species is for the Netherlands as a whole and not for the Lake IJssel complex
Lake Karla	No regular monitoring data available on non-bird species. Presence of 16 fish species.	Records of circa 200 bird species. The lake is a base for some endangered species like Dalmatian pelican (*Pelecanus crispus*).	Refilling the lake has revived the location for bird and fish biodiversity (including invasive fish species). 50 bird species under Directives 2009/147/EC and 92/43/EEC and are all in good conservation status. 4 fish species under Directives 2009/147/EC and 93/43/EEC, 1 in good conservation status and 3 in average or reduced. In parallel, there are also records of otter (*Lutra lutra*).
Loch Leven	Diverse macrophyte community that declined in richness in the most eutrophic period (1960s to 1990s) and an improving trend in richness, area coverage and maximum growing depth post-2000	The last published assessment from 2009 indicated all 9 designated bird species were maintaining favourable condition.	Improvement in water quality and clarity appear to have contributed to improvement in the richness and abundance of aquatic plants. Improving trends in 5 bird species and pollution intolerant benthic invertebrate species are also reported along similar timescales to the trends in improving water quality and macrophyte habitats.

Funded by the European Union

Lake Vansjø	Favourable condition has been reported for several species like moor frog and cray fish	206 bird species were recorded between 2000 and 2025, of which 58 are red listed according to the Norwegian red list. In *Moskjæra* drone observations did not indicate nesting birds.	The impact of restoration measures on biodiversity is largely unknown. The bird species diversity appears to be maintained including breeding pairs of fish-eating ospreys.

3.2.3 Zero pollution; priority substances

The results for zero pollution are discussed under three categories: heavy metals, microplastics and PFOS.

Heavy Metals

No data were presented on heavy metals in five Demonstration Sites (DS-Annexes a to e). **Lake Vansjø** is the exception, where in the Vanemfjorden part, in 1999, Hg concentrations in pike muscle tissue were analyzed and its content was determined to be 730 µg/kg wet weight. In 2000, Hg was quantified in the muscle tissue of zander – 220 µg/kg wet weight and perch – 440 µg/kg wet weight. Mercury content studies in the perch population in Storefjorden were performed in 2014 - 2016. In the liver of these fish, mercury concentrations ranged from 317.0 to 598.4 µg/kg wet weight. Environmental Quality Standards (EQS) indicate the permissible level of mercury in organisms at 20 µg/kg wet weight. Thus, the results from **Lake Vansjø** are considered very high, exceeding the permissible standards many times.

Microplastics

Data on the presence of microplastics in FutureLakes Demonstration Sites is scarce. In **Lake Vesijärvi**, bottom sediments were examined for microplastic content in areas adjacent to urban areas. 400 MPs/kg were recorded (Scopetani et al. 2019). Snow (120 MPs/l of snow) and ice (8 MPs/l of ice) were also examined. Microplastics consisted of synthetic fibers, which constituted >99% and fragments <1%. No foils, granules, or pellets were detected. It was assumed that the main source of microplastics was fibers released from clothing during recreational use of the lake. Microplastic content is likely lower in lake bays, where the edges are less urbanized. MPs have also been detected in zooplankton samples taken from Enonselkä Bay but their volume has not been assessed.

There are no precise data on microplastics in the **Lake IJssel complex**, but Margaret Schoor (advisor for Ecology and Water Quality at Rijkswaterstaat) estimates that between 60 and 70 million pieces of plastic entered Lake IJssel via the IJssel River in 2023.

In **Lake Vansjø,** water was analyzed for microplastics both before and after treatment. Tests revealed the presence of 2-3 particles per liter of water, which was considered low and did not constitute a restriction on the use of water from the lake for water supply purposes.

Microplastic data was not available for the other lakes. It is a relatively new kind of assessment and is not standard in typical lake monitoring in EU countries. Microplastics assessment could be included in future water monitoring strategies.

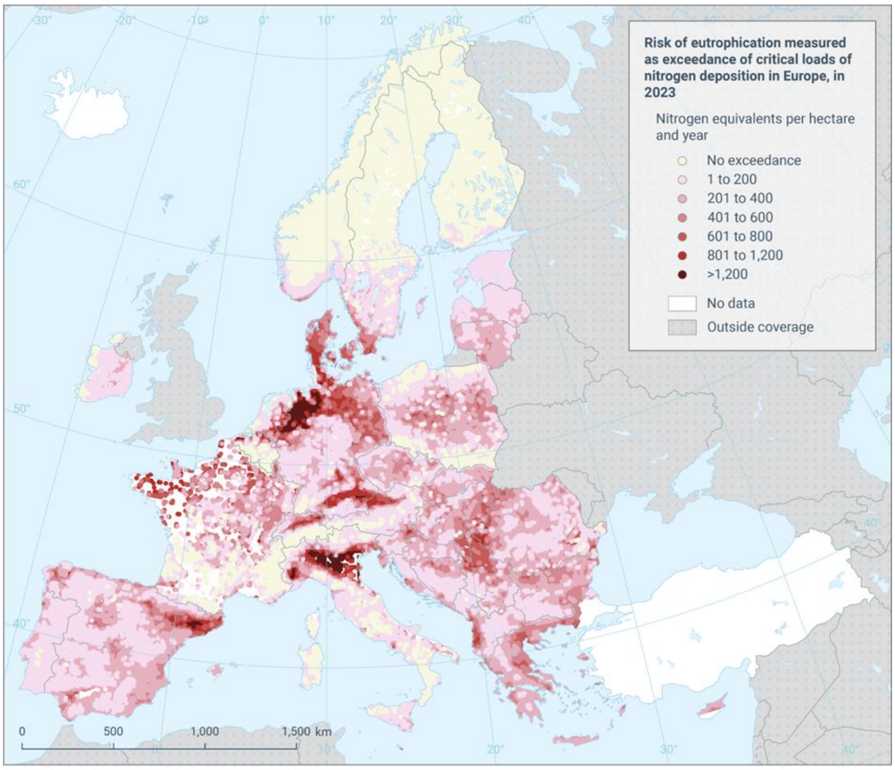
PFOS

In the case of **Lake Vesijärvi**, it is not possible to assess the trend in PFAS occurrence, as only one PFAS analysis result is available, from the lake's catchment area. PFAS levels of 3070 ng/g (of 2150 ng/g PFOS) were recorded in the muscle of perch from Kajaanselkä Bay, resulting in Lake Vesijärvi being designated as an area with high PFAS contamination. The suspected sources of contamination are two sewage treatment plants, two pulp mills, and a waste incinerator in the catchment area.

The chemical condition of **Lake Vansjø**'s Storefjorden Bay has been deemed poor due to PFOS contamination. The persistent chemicals mainly originate from fire extinguishers used at the Rygge Military Airport, which adjoins the lake. While the use of fire extinguishers has been discontinued, PFOS will remain in the lake for many years to come. Bottom sediment was collected from Storefjorden Bay (eastern part of Lake Vansjø) in 2006. Analysis showed that they contained an average PFOS concentration of 1.9 µg/kg d.w., which is above the AA-EQS (average annual threshold) and below the MAC-EQS (maximum annual concentration). Simultaneously, muscle tissues of roach, pike, and perch were analyzed, and concentrations of 7.5, 24.8, and 57.2 µg/kg d.w., respectively, were recorded. The latter two values are above the EQS standards for organisms, although the liver is the matrix preferred by PFOS. In the Storefjorden section of Lake Vansjø, PFOS concentrations averaged 173 µg/kg dw in 2014 and 346.2 µg/kg dw in 2015, exceeding the EQS for organisms at 9.1 µg/kg dw. The final site for PFOS testing in Lake Vansjø was the narrow bay between Storefjorden and Vanemfjorden, where persistent chemicals were analyzed in bottom sediments and pike muscle tissue. The bottom sediments contained PFOS at levels of 1.15 µg/kg dw. i.e., above AA-EQS (0.23 µg/kg d.w.), but below MAC-EQS (72 µg/kg d.w.). Recent evaluations (2020-2021) of pike, perch and pikeperch tissue samples showed values of 9.1 µg/kg d.w., which was also above the EQS thresholds.

3.2.4 Zero pollution; nutrient loading

The average P load from the atmosphere into water in Europe was assessed as 0.29 kg P/ha/year (Pan et al. 2021). As demonstrated in Figure 7, the risk of exceeding N atmospheric deposition is higher in areas of intensive agriculture. In some areas of Europe, N atmospheric deposition is enough to support high primary production in surface waters separately to other sources.



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commision – Eurostat/GISCO

Figure 7: Map of eutrophication risk of European waterbodies due to nitrogen (N) atmospheric deposition measured as exceedance of critical loads in 2023. Source: EEA (2025).

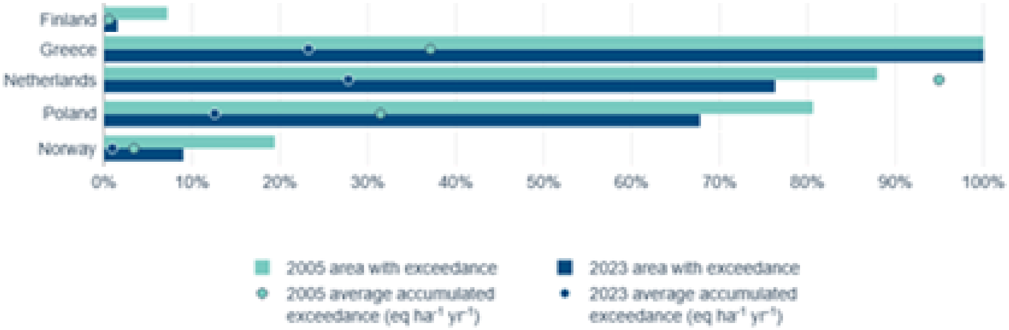


Figure 8: Eutrophication caused by atmospheric nitrogen deposition in Europe. Adapted from EEA (2025).

In the case of **Lake Vesijärvi**, the reduction of external loading was assessed (since 1991) from 2752.2 mg N/m^2/year to 2277.6 mg N/m^2/year for nitrogen compounds. Estimated external phosphorus loads were also lower (from 137 mg P/m2/year in 1991 to 120.9 mg P/m^2/year now) (Figure 9, Figure 10 and Table 6). For both nutrients, external loading falls below Vollenweider's critical loads level. Therefore, Lake Vesijärvi seems to have the highest resistance level against diffuse pollution amongst all six Demonstration Sites, whilst also having a low proportion of agricultural land in the catchment area. Nitrogen deposition from the atmosphere in Finland is the lowest among all Demonstration Site countries. It should be noted that an operational, national-scale nutrient load model WSFS-Vemala (Huttunen et al. 2016) suggests orders of magnitude higher annual loads of P (223 mg P/m^2/a) and N (4582 mg N/m^2/a) to Lake Vesijärvi, respectively. Furthermore, a national Lake Load Response model (Kotamäki et al. 2015) suggests lower critical loading levels (130 mg P/m^2/a and 2595 mg N/m^2/a, respectively) compared to Vollenweider's estimates (Figure 9, Figure 10, Table 6). This national model indicates that the critical loads to Lake Vesijärvi are exceeded and reductions of ca. 93 mg P/m^2/a and 1988 mg N/m^2/a would still be required to manage external loading within tolerable boundaries.

The present total P loading is below critical load for three **Kartuzy Lakes** (Mielenko, Klasztorne Małe Lake and Klasztorne Duże Lake). For the Lake Karczemne, Vollenweider's critical loads are currently exceeded (Figure 9, Figure 10 and Table 6). The restoration measures which were applied in the Kartuzy Lakes catchment (sewage cut-off, sewerage system modernization) were able to successfully decrease the external nutrient loadings.

The assessed nitrogen loading to **Lake IJssel** (via IJssel River) decreased from almost 43000 mg N/m^2/year (in the 1970's) to 6000 mg N/m^2/year (present values), and from 4171 mg P/m^2/year to 225.3 mg P/m^2 year (archive data for 1970's from Frenken et al. 2023). The current loading for the Lake IJssel complex is shown in Figure 9, Figure 10 and Table 6. The external loads of nutrients decreased amongst others due to wastewater treatment developments and catchment measures (DS-Annex c).

In the case of **Loch Leven**, a substantial decrease in the external nutrient loadings for N and P was observed. Although present N loadings still exceed Vollenweider's critical level (Figure 9, Figure 10 and Table 6).

Historical nutrient loadings were not available for **Lakes Karla** and **Vansjø**, although it is possible that the external nutrient inputs were higher in the past as this was noted for other Demonstration Sites. The development of wastewater treatment infrastructure was made in every Demonstration Site catchment in the past, as described in the DS-Annexes a-f. Also, for example, EEA reported, that the atmospheric N deposition was lower in the Demonstration Sites countries, as shown in Figure 8. Hence, we can assume some nutrient loading reduction to the Lakes Karla and Vansjø. The assessed current loadings for these sites are higher than the critical N and P levels, indicating that the protective measures in the catchment of both lakes may be insufficient. In the catchment of both lakes, sewage treatment plants were constructed (DS-Annexes d and f) and wastewater management is developing.

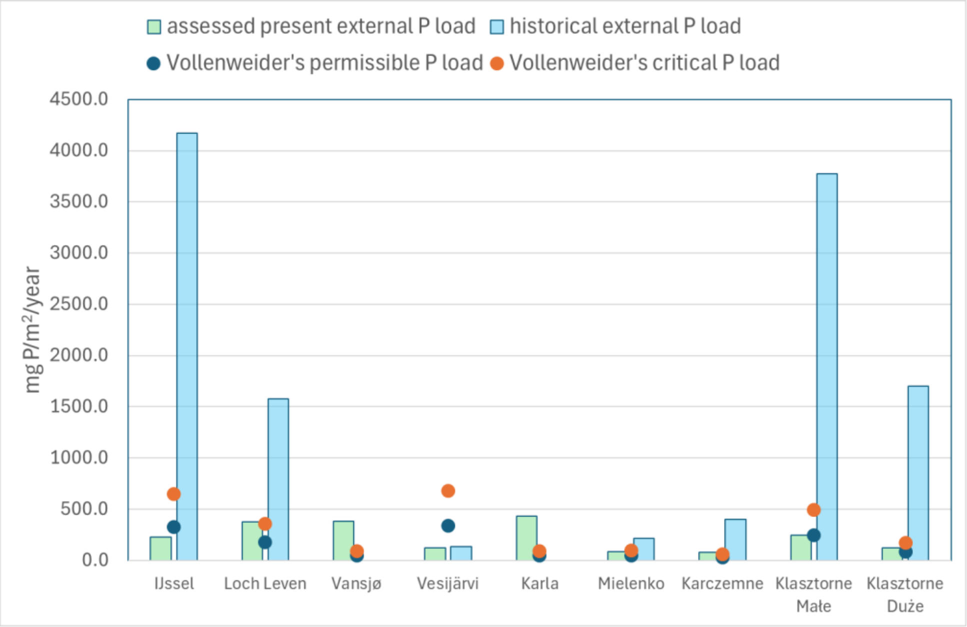


Figure 9: Assessed current phosphorus loading to Demonstration Sites from land and atmospheric sources compared to Vollenweider's permissible and critical P loads based on Vollenweider model (1976) (present loads as the sum of loads from land and atmospheric sources, with exception of Kartuzy Lakes, where all present loads were assessed; no historical data about loads were available for Vansjø & Karla)

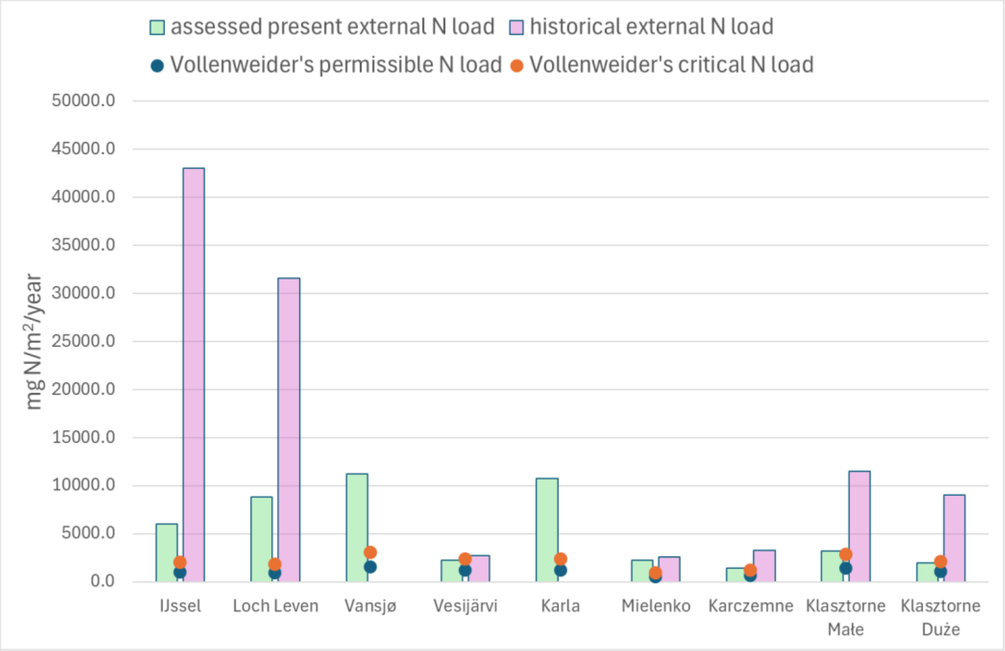


Figure 10: Assessed present nitrogen loading to Demonstration Sites from land and atmospheric sources in comparison to Vollenweider's permissible and critical P loads, based on Vollenweider model (1968) (no historical data about loads were available for Vansjø and Karla)

Funded by
the European Union

Table 6. Estimated external nutrients loading reduction after implementing protective measures in the catchment of Demonstration Sites.

Demonstration Site		External loading reduction since beginning of restoration measures		Present Vollenweider's critical load exceeding	
		Total P	*Total N*	*Total P*	*Total N*
Lake Vesijärvi		🟨	🟨	🟩	🟩
Kartuzy Lakes	**Karczemne**	🟦	🟩	░	░
	Klasztorne Małe	🟦	🟩	🟩	░
	Klasztorne Duże	🟦	🟩	🟩	🟩
	Mielenko	🟩	🟧	🟩	░
Lake IJssel complex		🟦	🟦	🟩	▒
Lake Karla				█	█
Loch Leven		🟩	🟩	░	█
Lake Vansjø				█	▓

Legend				
	above 75%	🟦	no excess	🟩
	50%-75%	🟩	up to 100% excess	░
	25%-50%	🟨	100-200% excess	▒
	0-25%	🟧	200-300% excess	▓
	no historical data		300-400% excess	█
			400-500% excess	🟫

3.3 Climate outcomes

3.3.1 Climate regulation

The overall methane (CH_4) emission from **Lake Vesijärvi**, estimated for 1974-2025 using the Bayesian modelling approach, was found to be 0.690 Gg CH_4-C/year (27,498 t CO_2-eq/year). In contrast, when IPCC guidance was used to calculate this value, the CH_4 emission was estimated to be 15,914 t CO_2-eq/year – 42% lower than that derived using the Bayesian method. **Error! Reference source not found.** shows the temporal variation and levels of uncertainty within the dataset that underpin these calculations. The 'before' and 'after' restoration comparison for this Demonstration Site is shown in Table 7.

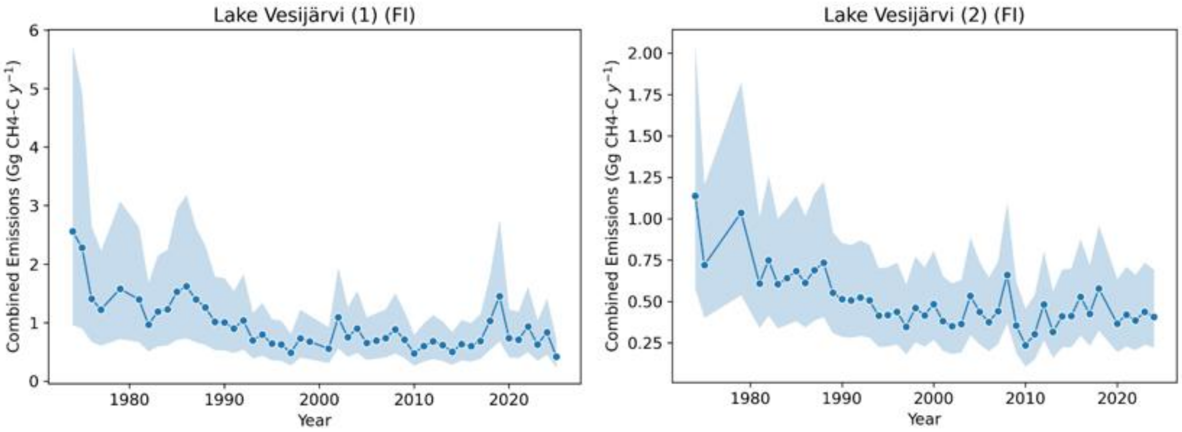


Figure 11: Combined ebullitive and diffusive methane (CH_4-C) emissions from the two main basins of Lake Vesijärvi, predicted from average summer chlorophyll a concentrations (June - September) using the Bayesian model. 95 % credible intervals (a Bayesian measure of uncertainty) are indicated in blue shading.

The overall CH_4 emissions from the **Kartuzy Lakes**, estimated for 2019-2025 using the Bayesian modelling approach, were found to be 0.48 Gg CH_4-C/year (1,912 t CO_2-eq/year). In contrast, when IPCC guidance was used to calculate this value, the CH_4 emissions were estimated to be 174 t CO_2-eq per year. This value is 91% lower than that derived using the Bayesian method. Figure 12 shows the temporal variation and levels of uncertainty within the dataset that underpin these calculations. The 'before' and 'after' restoration comparison across all Demonstration Sites is shown in Table 7.

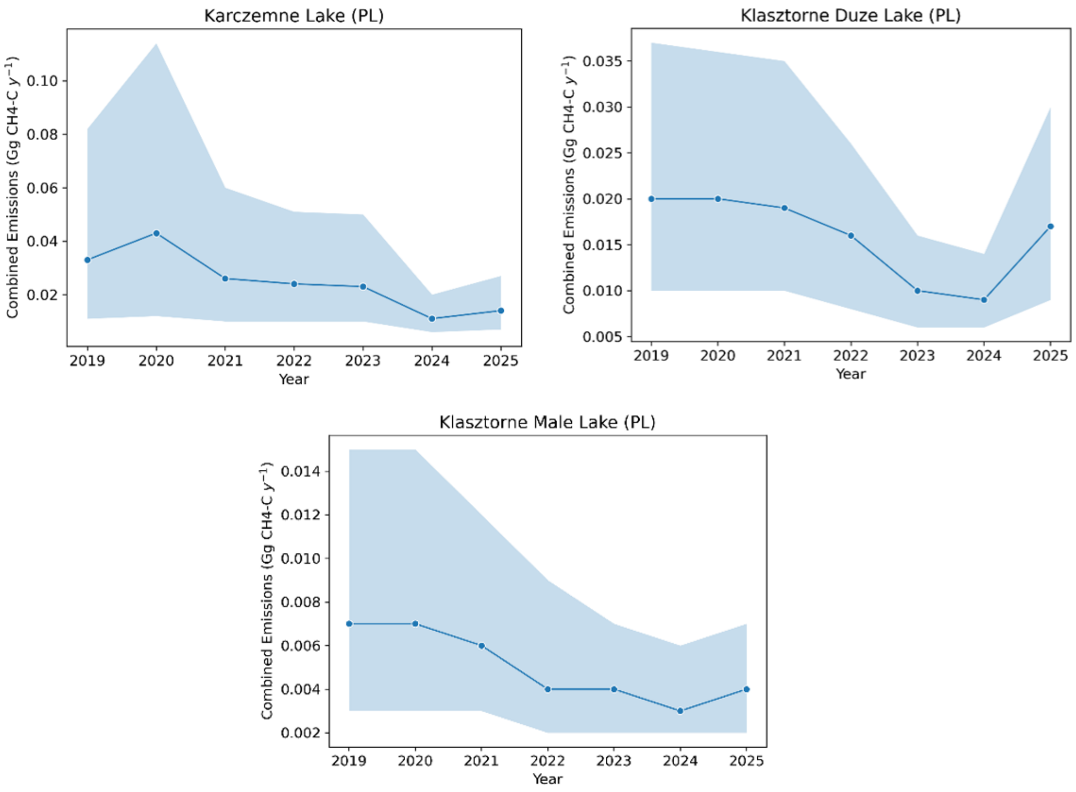


Figure 12: Changes in combined (ebullitive and diffusive) methane (CH_4-C) emissions for Lakes Karczemne, Klasztorne Duze and Klasztorne Male (Kartuzy Lakes), calculated from their annual average

chlorophyll a concentrations using the Bayesian model. 95 % credible intervals (a Bayesian measure of uncertainty) are indicated in blue shading.

The CH_4 emission from the **Lake IJssel complex**, estimated for 2005-2023 using the Bayesian modelling approach, was found to be 87.2 Gg CH_4-C/year (3,472,853 t CO_2-eq/year). This contrasts markedly with that calculated using the IPCC guidance value, i.e. 263,661 t CO_2-eq/year – a value that is 92% lower than that derived using the Bayesian method. Figure 13 shows the temporal variation and levels of uncertainty within the data that underpin these calculations. The 'before' and 'after' restoration comparisons for this Demonstration Site are shown in Table 7.

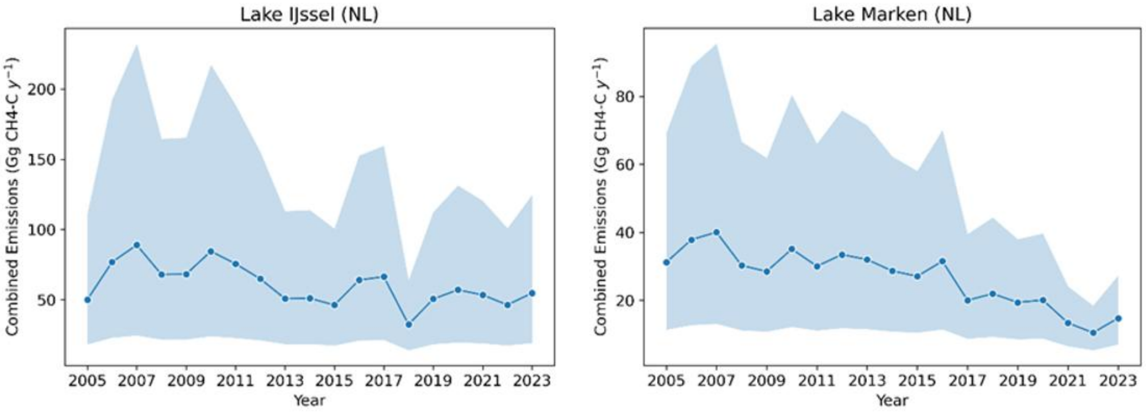


Figure 13: Changes in the combined (ebullitive and diffusive) methane (CH_4-C) emission estimates for Lakes IJssel and Marken within the Lake IJssel complex calculated from their annual average chlorophyll a concentrations using a Bayesian model. 95 % credible intervals (a Bayesian measure of uncertainty) are indicated in blue shading.

The overall CH_4 emission from **Lake Karla**, estimated for 2013-2023 using the Bayesian modelling approach, was found to be 3.206 Gg CH_4-C/year (127,739 t CO_2-eq/year). In contrast, when IPCC guidance was used to calculate this value, the CH_4 emission were estimated to be 5,099,050 t CO_2-eq/year which as 3892% higher than that derived using the Bayesian method. Figure 14 shows the temporal variation and levels of uncertainty within the dataset that underpin these calculations. The 'before' and 'after' restoration comparison for this Demonstration Site is shown in Table 7.

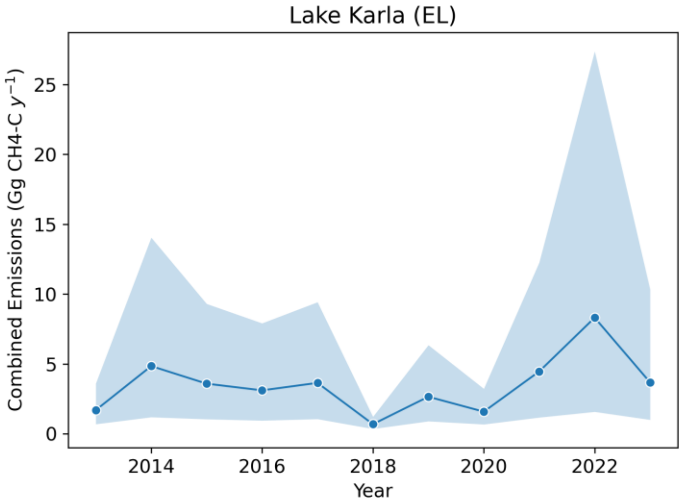


Figure 14: Combined ebullitive and diffusive methane (CH_4-C) emissions for Lake Karla based on average annual growing season (May - September) chlorophyll a concentrations, estimated using the Bayesian model. 95 % credible intervals (a Bayesian measure of uncertainty) are indicated in blue shading.

The overall methane (CH_4) emission from **Loch Leven**, estimated for 1968-2024 using the Bayesian modelling approach, was estimated to be 0.676 Gg CH_4-C/year (26,932 t CO_2-eq/year). In contrast, when IPCC guidance was used to calculate this value, the CH_4 emissions were estimated to be 1,942 t CO_2-eq/year a value that is 9% lower than that derived using the Bayesian method. Figure 15 shows the temporal variation and levels of uncertainty within the dataset that underpins these calculations. The 'before' and 'after' restoration comparison for this Demonstration Site is shown in Table 7.

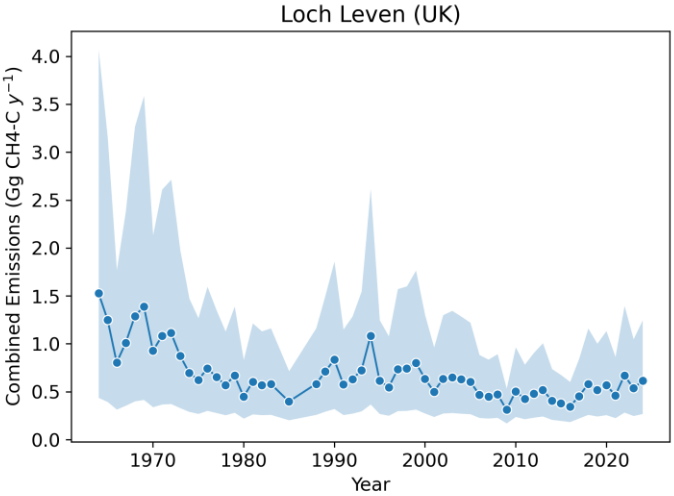


Figure 15: Combined ebullitive and diffusive methane (CH_4-C) emissions from Loch Leven based on average annual chlorophyll a concentrations, estimated using the Bayesian model. 95 % credible intervals (a Bayesian measure of uncertainty) are indicated in blue shading.

The overall CH_4 emission from **Lake Vansjø**, estimated for 1979-2024 using the Bayesian modelling approach, was found to be 0.305 Gg CH_4-C/year (12,160 t CO_2-eq/year). The equivalent value estimated using when following the IPCC guidance was 5,227 t CO_2-eq/year, which was 57% lower than that predicted using the Bayesian method. Figure 16 shows the temporal variation and levels of uncertainty within the dataset that underpin these calculations. The 'before' and 'after' restoration comparison for this Demonstration Site is shown in Table 7.

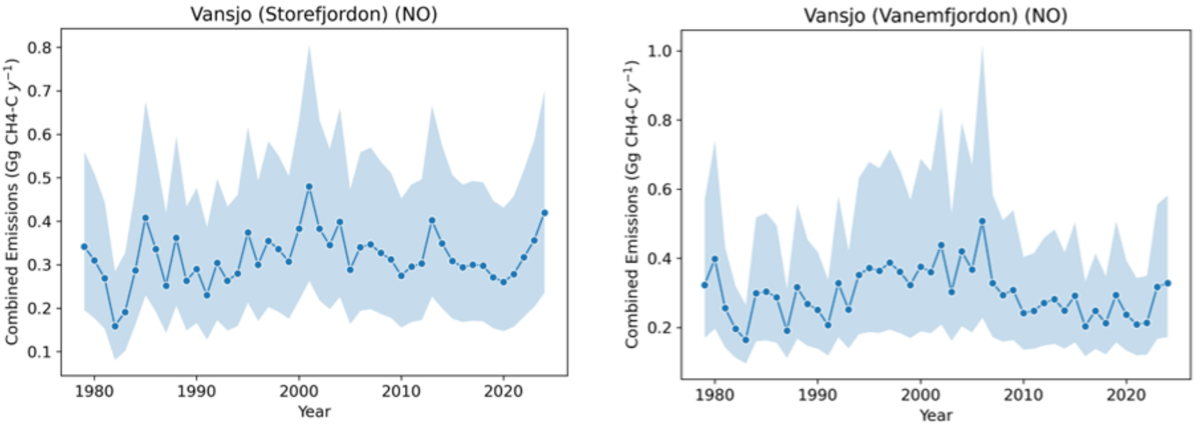


Figure 16: Combined ebullitive and diffusive methane (CH_4-C) emissions from the two main basins of Lake Vansjø, predicted from average summer chlorophyll a concentrations (June - September) using the Bayesian model. 95 % credible intervals (a Bayesian measure of uncertainty) are indicated in blue shading.

Table 7: Estimated changes in annual CH_4-C emissions, estimated using the Bayesian model, before and after restoration at the Demonstration Sites. 'Before' data are the earliest available records for each lake; 'after' data are the most recent available records – 10 years where possible.

Demonstration Site	Before/after restoration	Data used	Estimated emission (Gg CH_4-C/y)	Estimated change in emission (%)
Lake Vesijärvi	Before	1979-1988	1.116	+50%
	After	2016-2025	0.556	
Kartuzy Lakes	Before	2019	0.063	+46%
	After	2023-2025	0.034	
Lake IJssel complex	Before	2005-2016	97.923	+47%
	After	2017-2023	51.555	
Lake Karla	Before	Lake bed dry	0	No data
	After	2013-2023	3.206	
Loch Leven	Before	1968-1984	0.871	+57%
	After	2005-2024	0.489	
Lake Vansjø	Before	1979-1988	0.257	-10%
	After	2015-2024	0.283	

This represents an estimated overall decrease of 44.1 Gg CH_4-C/y across the Demonstration Lakes due to the restoration measures implemented.

Comparison of methods

The estimated annual average emissions of CH_4 from the study lakes is shown in Table 8. In general, the Bayesian method estimated emission values for each lake that were 10-14 times higher than those estimated using the IPCC method. This suggests that the IPCC method currently being used may be underestimating the level of contribution to global warming driven by these emissions.

Table 8: Estimated CH_4 emissions from the study lakes calculated using two different methods, Bayesian and IPCC

Demonstration Site	Surface area (ha)	Bayesian estimate (t CO2-eq/y)	IPCC estimate (t CO2-eq/y)	Ratio of Bayesian *cf.* IPCC estimates
Lake Vesijärvi	10,700	27,498	15,914	1.73
Kartuzy Lakes	119.4	1,912	174	10.97
Lake IJssel complex	180,590	3,472,853	263,661	13.17
Lake Karla	3,492,500	127,739	5,099,050	0.03
Loch Leven	13,300	26,932	1,942	13.87
Lake Vansjø	3,580	12,160	5,227	2.33

The combined CH_4-C emissions from all of the Demonstration Sites, calculated over a standardised area of one square metre, are compared in Figure 17. The total emissions estimated from each lake varied among the Demonstrations Sites with higher emissions being predicted from the larger lakes. However, Figure 17 shows that the emissions per unit area also differed among these lakes with some (e.g. Lake Vesijärvi and Lake Vansjø) having values of less than 0.05 kg CH_4-C/m2/y while the estimated emissions from Loch Leven were consistently higher (up to 0.1 kg CH_4-C/m^2/y).

The combined CH_4 emissions per unit area of lake surface are compared for all of the Demonstration Sites in **Error! Reference source not found.**. The data show that CH_4-C emissions per unit area differ enormously from lake to lake, strongly suggesting that the one one-size-fits-all approach based on lake area proposed in the IPCC guidance is an oversimplification of reality that leads to CH_4 emissions from lakes being incorrectly estimated.

There are very few measured CH_4 emissions data for the Demonstration Sites. However, some do exist for Lake Vesijärvi and Loch Leven. These are 2,090 t CO_2-eq/y (Lopez Bellido et al., 2011) and 4,013 CO_2-eq/y (unpublished data, 2022-2024), respectively – values that differ, again, from the values predicted by the Bayesian and IPCC models (**Error! Reference source not found.**). This also suggests that more work is needed to validate these models before they can be used confidently in large scale greenhouse gas assessments.

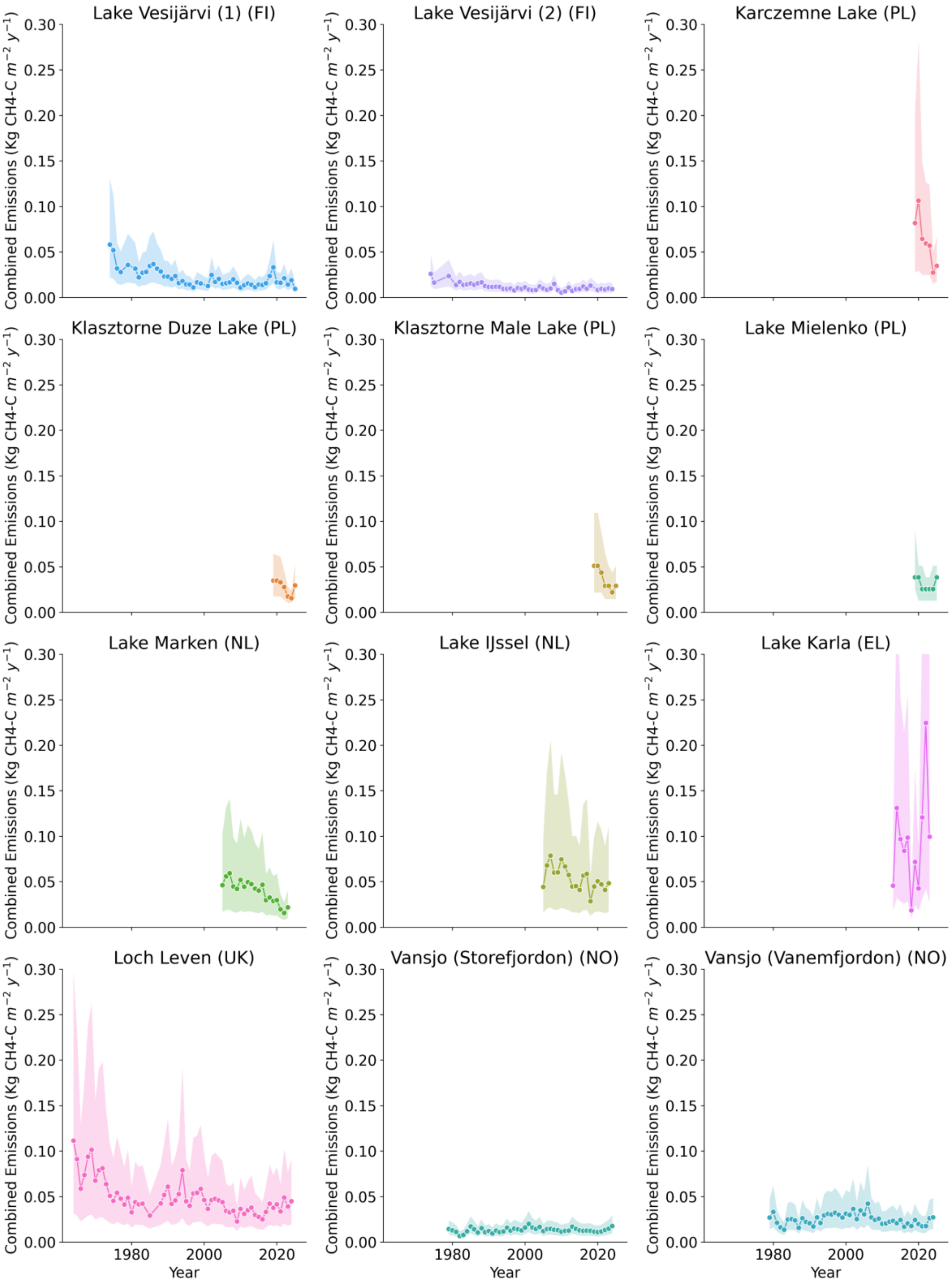


Figure 17: Combined emissions of CH_4-C per unit area (kg m^{-2} y^{-1}) across all Demonstration Sites, estimated using the Bayesian method.

3.3.2 Climate resilience

Lakes provide ecosystem services that increase the resilience of their catchments to climate change. We have focused on ecosystem services related to drought and flood resilience.

No changes in **Lake Vesijärvi** area have occurred over recent decades that would affect the lake's water storage capacity. The lake has been regulated by a dam on its outflow since 1925 keeping the water level at 81.06 – 81.35 m above sea level, so there has been no change in the lake volume for a century. Moreover, the in-lake restoration efforts of Lake Vesijärvi have not affected the lake's water storage or retention capacity. However, the external water protection solutions such as constructed wetlands, restoration of streams and a stormwater management programme in the City of Lahti contribute to flood and drought mitigation by reducing the volume of waters discharging to the lake.

The **Kartuzy Lakes** water supply system is an open-circuit ring system, with water being distributed to approximately 32,000 residents *via* 37 wells and 13 water treatment plants. In the Kartuzy area, surface water is not used for water supply and groundwater resources are not under threat from climate change.

The **Lake IJssel complex** provides water supply for citizens, crops and livestock, space for wildlife, recreation and transportation. The water levels of the lake complex are constantly monitored and adjusted to maintain water supply services. Under drought conditions, water allocation is prioritised to deliver water to the most vital elements of Dutch society. In contrast, when there is a possibility of flooding, water is pumped out of the lake to reduce the risk. Programmes are in place to ensure water security under different climate change scenarios.

The **Lake Karla** area follows the National Strategy on Climate Adaptation plan that was introduced in March 2025. NbS (wetland re-establishment, riparian restoration, reedbeds, buffer strips) were combined with targeted engineering (embankments, controlled storage) to manage floods and droughts while delivering ecosystem services. However, since 2023, there have been calls for systemic change: strengthening flood defences, re-thinking floodplain use, moving dykes, restoring river connectivity, restricting new construction on floodplains, and reconsidering water-hungry cropping (e.g. cotton) to increase resilience to climate change.

At **Loch Leven**, the water level was reduced by 1.4m when sluice gates were installed on the outflow in 1850. The outflow was also straightened to increase the rate of flow. Although these engineering works were put in place to supply a reliable source of water for industrial use downstream, these industries no longer exist and the sluice gates are now managed to maintain pre-agreed water levels within the loch, providing climate change resilience.

Flooding is a frequent occurrence around **Lake Vansjø** and its catchment. It has been documented that the implemented nutrient mitigation measures would have been even more effective if the year 2000 flood had been prevented. To increase climate resilience, the outlet capacity of the lake should be increased, e.g. by building a flood tunnel, at estimated cost of appr. M€ 8.8. It has also been suggested that rivers within the catchment need to be made more resilient to erosion and flooding, at an estimated cost of appr. M€ 9.

Overall, climate change resilience was demonstrated at all Demonstration Sites through monitoring and strategic water management. Nature-based solutions (wetland restoration, river connectivity, floodplain use, buffer strips, etc.) have been combined with targeted engineering works (embankments, controlled storage) to reduce the impacts of droughts and floods while continuing to deliver ecosystem services.

3.4 Societal outcomes

Lake restoration projects consistently deliver benefits beyond ecological recovery, significantly enhancing cultural/recreational ecosystem services, and bolstering community well-being. The synthesis of social outcomes and recreational benefits across the six Demonstration Sites confirms that the extent of societal and recreational benefits is strongly linked to water quality improvements, supportive infrastructure and inclusivity in management. Which of these three had greatest impact on tourism is very hard to disentangle. It is likely that infrastructure – providing accessibility – had a greater impact on tourism levels than water quality improvements.

The restoration trajectories across the six Demonstration Sites expectedly reveal some differences depending on the targets of restoration programmes. In Lake Karla and Lake IJssel complex, the main restoration effects target mostly habitat restoration and biodiversity conservation on these complex ecosystems. On the other hand, in Lake Vesijärvi, Lake Vansjø, Loch Leven, and Kartuzy Lakes, the primary driver of restoration is focused on water remediation, the improvement of water quality and the development of infrastructure to support direct human uses, such as drinking water supply, safe bathing waters and intensive recreational activities.

3.4.1 Health and well-being

Across the Demonstration Sites, restoration has significantly influenced how local communities use and experience their lakes. In Lake Vesijärvi, the initial recovery was driven by sewage diversion and improved sanitation, after which biomanipulation and efforts to manage diffuse nutrient inputs became the central restoration strategies. As water quality improved, recreational activities gradually returned to the lake. Lake Vansjø is distinctive as a direct source of drinking water, supported by advanced treatment technology and continuous monitoring. These measures not only safeguard water quality but also enable extensive recreational use, including swimming and water sports.

A similar pattern occurred in the Kartuzy Lakes, where extensive sewage diversion and sanitation upgrades formed the foundation of the restoration programme. The resulting improvements allowed the reopening of public beaches and stimulated waterfront development. At Loch Leven, a suite of wastewater treatment improvements played a key role in the lake's recovery. These interventions have led to safe water contact conditions for much of the time and supported year-round recreation, although recent years, dense blooms of harmful cyanobacteria in some summers has restricted recreational use involving direct water contact.

The Lake IJssel complex—an important drinking water source—already supports extensive recreational use. However, the water quality at bathing sites can be challenged during heavy rainfall events that wash bird droppings and other materials from the shoreline into the lake. In contrast, Lake Karla is currently used primarily for agriculture. Here, restoration has strengthened nature connection, improved wellbeing and enhanced water security for local farmers, although these gains remain constrained by ongoing restrictions. Recreational use of the lake is still low and largely occasional.

Table 9 gives an overview of the six Demonstration Sites presenting their bathing water quality and water related activities. The mentioned activities are not (environmental) measures aimed at lake restoration. The activities are mostly facilitated by infrastructural measures providing access to the lakes. The activities can be considered as societal outcomes of the environmental measures since people will not perform recreational water-related activities when the water quality is extremely poor (algal blooms, dying fish etc).

Table 9. Overview of Demonstration Sites presenting Bathing water quality and recreational use.

Demonstration Site	Bathing Water quality	Water-related and other recreational activities
Lake Vesijärvi	Excellent/Good (elimination of bathing bans)	Year-round swimming, routes, winter skiing, triathlons (approx. 10k athletes and staff), fishing, harbour, summer housing, boating, birdwatching
Kartuzy Lakes	Improved quality in the last years but swimming is discouraged (public beach expected to open in 2026)	5km promenade, summer activities SUP hiking paths, summer-oriented, water bike rentals, photography
Lake IJssel complex	Varies from excellent to not suitable for swimming	Extensive sailing, long distance trails, 40+ bathing spots, boating and fishing networks attracting nearly half a million sport fishers occasionally. Widespread swimming, angling, (kite) surfing and boating.
Lake Karla	Not applicable since swimming and water sports are prohibited	Occasional hiking biking photography and birdwatching
Loch Leven	Good (supports safe water contact activities)	All ability Heritage Trail, mobility scooter rental available, (kayaking, paddleboarding, angling), bird hides
Lake Vansjø	Good (high recreational value, bathing bans due to cyanobacterial blooms occur more rarely)	Hiking paths, skiing, ice-skating, widespread swimming in some parts of the lake, angling, and boating. community-maintained paths

3.4.2 Inclusivity

Table 10 below ranks inclusivity in lake management by the ability of the Demo sites to foster inclusivity in their lake governance. Governance arrangements span from very inclusive, multi-actor, multi-sectoral approaches, also actively involving the public, to more centralised models. In general, participatory water management, when combined with coherent national regulation, broad public awareness and effective knowledge sharing, tends to deliver the most successful and resilient outcomes.

Table 10. Inclusivity in restored waterbody management from highly inclusive/bottom-up to centralised/top-down control. The darker the shade, the stronger is the inclusivity in lake management.

Demonstration Site	Inclusivity in lake management
Lake Vesijärvi	Multi-sector inclusive. More than 100 stakeholders' organizations (municipalities, NGOs, private sector, research institutes). Multi-sector collaboration.
Kartuzy Lakes	Mixed model/Local collaboration. Meaningful engagement among local authorities, residents, NGOs, but institutional fragmentation remains a barrier.

Lake IJssel complex	Numerous NGOs, but decision-making around nature conservation and/or recreation can be challenging because lake is used as a strategic water resource of freshwater for drinking and agriculture.
Lake Karla	Centralised top-down control, limited stakeholder engagement, but local engagement seems to be increasing.
Loch Leven	Mixed model/conservation-led integrated management by organizations, locals and public agencies within the National framework.
Lake Vansjø	Strong multi-level collaboration through Morsa Water Board. Local collaboration. Up to 75% of local farmers are in environmental contracts around Vanemfjorden.

3.4.3 Recreation

Recreational effects seem to follow a gradient of three levels, with Demonstration Sites Lake Vesijärvi, Loch Leven, Lake Vansjø and the Lake IJssel complex supporting the most diverse and intensive recreation activities, Kartuzy Lakes representing the transformation towards emerging recreation activities and Lake Karla remaining the most restricted system, where water-based activities are prohibited and recreation is limited (Table 11). The main recreational activities and more specific tourism characteristics, such as the type of available infrastructure, accessibility and the number of visitors are presented below (Table 12).

Table 11. Recreational gradient across lakes.

Demonstration Site	Recreational intensity			Nature-oriented recreation			Infrastructure to promote nature recreation			Seasonality		
	High	Moderate	Low	Strong	Growing	Limited	High	Developing	Low	All-season	Season-focused	Irregular
Lake Vesijarvi	X			X			X			X		
Kartuzy Lakes		X			X			X			X	
Lake IJssel complex	X			X			X			X		
Lake Karla			X			X			X			X
Loch Leven	X			X			X			X		
Lake Vansjø	X			X			X			X		

Table 12. Summary of recreation and available tourism metrics across lakes.

Demonstration Site	Recreational Intensity	Main activities	Type of infrastructure	Accessibility	Number of visitors/ Type of tourism/ Frequency or Duration of visit
Lake Vesijärvi	High/ Multidimensional	Sports activities (walking, hiking etc.), triathlons, recreational fishing, swimming, skiing, birdwatching	Public beaches, 180 km of outdoor routes and skiing tracks, 30 km nature trails, 4 bird hides for birdwatching, passenger harbour, summer, >1,300 cottages/holiday apartments	Lahti/Enonselkä basin is the center of many recreational services, available linkage between waterways and marinas.	Annually 9,000 recreational fishermen (75% in wintertime), 10,000 athletes and staff attending the triathlon events (until 2023), holiday apartments availability encourage long stays. Year-round activities.
Kartuzy Lakes	Moderate/ Emerging (Developping)	Waterfront use, SUPs, cycling, angling, promenades, hiking paths, pedestrian paths (5 km), water bikes	5 km hiking/ pedestrian paths, small-scale architecture elements (benches, info boards etc.), 14 hotels and apartments close to the lakes, restaurants, cafeterias. City beach opening planned before summer 2026.	Paths safe for wheelchair users, cyclists and pedestrians. Supported by public and rail transport linkages.	Increasing demand, growing short-term rentals and new infrastructure for staying. Mostly summer use, in transition from limited use to an actively developed waterfront. Proximity of Kartuzy to Tricity (Gdańsk, Sopot and Gdynia) is also favourable for recreational uses. It is recommended by tourist information centers.
Lake IJssel complex	High/ Multidimensional	Recreational fishing, water sports, boating, sailing, angling, cycling, birdwatching, swimming, tourism, canoeing, SUPs	130 marinas (20,000 berths), 450 traditional ship sails, 25 holiday accommodations (campsites, bungalows, hotels, guest houses), (9,000 pitches), restaurants, paths, 40 official bathing locations, waterfront promenade for cycling and	Lake IJssel complex has extensive navigation and boating networks, there are transport regulations.	Nearly half a million sport fishers occasionally. Locals, visitors from the Netherlands and international ones. Available infrastructure for high visitor numbers and long stays, multiple recreational

Funded by the European Union

			walking, beaches, birdwatching locations, small and large attractions, long-distance walking trail, long-distance cycling route around the lakes.		activities support water-based tourism.
Lake Karla	Low/ Limited	Birdwatching, wildlife photo, occasional eco-tourism, outdoors activities/routes (running, cycling, horse-riding)	Dykes for hiking and cycling. Information center and exhibitions about local biodiversity. Local museums, 6 walking routes, limited number of cafeterias, canteens, restaurants (<5), 2-3 accommodation choices, in total 12 businesses provide touristic and recreational services.	Limited infrastructure, primary accessibility is through occasional land-based activities.	Approximately 2,000 visitors in lake area (2018), 1,000 visitors (2018) in the information center and in permanent exhibitions about local biodiversity, plus approx. presentations in 300 students from schools in the regional area. Schools, families and environmentally aware people (eco-tourism tours). Mostly daytrips, less than 400 overnight stays annually.
Loch Leven	High/ multi-dimensional	Walking, hiking, cycling, angling, kayaking, paddleboarding, birdwatching, cultural heritage (heritage trails), guided walks and tours (bumblebee trail, bat walk, boat tours, heritage tours)	Heritage trail, paths, wildlife hides, trails, visitor center accommodation available	Heritage trail: accessible route for walking, running and cycling and use of mobility scooters from all age groups, YouTube live streaming of red squirrel feeding station. Boat tours available. Low-emission mobility opportunities	Approx. 300,000 visitors annually. Year-round activities, locals, families with children, dog walkers, cultural tourists etc. Local accommodation available so trips longer than daily are possible.
Lake Vansjø	High/ Multidimensional	Swimming, angling, watersports, winter activities (ice-skating, skiing), hunting, fishing, canoeing, camping, hiking	Maps, routes, cabins, summer camps, beaches, marinas, upgraded hiking routes, farmhouses/farms, venues	Upgraded lit paths, appropriate for wheelchair users and strollers. Several venues close to the shore offer accommodation. Local transport available.	Outdoor activities, culture, summer camps for children

3.5 Economic outcomes

3.5.1 Costs of measures

The types of measures undertaken at the six Demonstration Sites are summarised in Table 13. Measures were classified by landscape in which they were applied (agricultural, urban, lake shoreline, in-lake, or other). The measures were also classified by the type of measure: NbS, CBS, BfS, Grey-infrastructure, land management, blue economy, or other. NbS measures in agricultural landscapes were the most common measures. Grey infrastructure measures in urban landscapes largely related to sewage treatment upgrades and stormwater management and Biodiversity-focused measures in-lake or along shorelines were also commonly implemented. Biomanipulation of fish communities was also a common in-lake measure. This typically involved removal of zooplanktivorous and benthivorous fish to reduce internal nutrient loading and re-structure the food web to increased macrophytes. Consequently, this measure can, therefore, be considered an NbS and BfS measure and sometimes even a CBS measure if the fish are sold for food/feed.

Table 13. Count of measures of different types at each Demonstration Site.

Demonstration Site	Land management	BfS	CBS	NbS	NbS / CBS	Blue Economy	Other	Total
Lake Vesijärvi				13	10		6	29
Kartuzy Lakes			1	1		1	5	8
Lake IJssel complex[1]		4		8[2]			1	13
Lake Karla		3		2		1	5	11
Loch Leven				1			6	7
Lake Vansjø				5			4	13
Total	**4**	**7**	**1**	**29**	**10**	**2**	**30**	**83**

1) Shoreline and in-lake measures only.

2) Making the lakes a more fish friendly environment has been grouped into one NbS measure, however, this measure consists of >20 fish passages and/or adjustments made to sluices.

A vast number of external measures at Demonstration Sites have been applied on either agricultural or urban landscapes and have represented different kinds of land management practices, and establishment of different water protection measures such as buffer strips, constructed wetlands and stormwater management structures (Table 14). Wetlands and sandbars have been established along the lake shorelines and transition zones. In-lake measures applied have included removal of different forms of lake biomass and sediment as well as creation of islands and doses of chemical precipitates for P inactivation.

Table 14. Number of measures applied at Demonstration Sites classified under landscape and type of measure.

Landscape	Measure	NbS	CBS	BfS	NbS / CBS / BfS	Grey	Land management	Blue Economy	Other
Agricultural N=24	Pond/wetland creation	10							
	Floodplain/Riparian restoration (incl. buffer strips)	9							
	Grass covered waterways	1							
	Grass on flood-prone areas	1							
	Catch crops						1		
	Environmental contracts						1		
	No tilling in autumn						1		
	Reduced use of fertilizers						1		
Urban N=15	Industrial waste discharge stopped								1
	Improved sewage treatment					10			
	Combined sewer overflows and stormwater management					4			
Shoreline N=6	Natural foreshore creation along dyke			3					
	Wetland creation/restoration (reed beds)			2					
	Sandbar & recreational zone construction			1					
	Sandbar construction			1					
In-lake N=22	Island creation					1			
	Refuge area (wind break dam)			1					
	Biomass removal - fish				8				
	Biomass removal - macrophytes			4					
	Sediment removal from lake		1						
	P inactivation agent doses								1
	Aeration								5
Other N=3	Barrier removal (connectivity)			1					
	Dyke to create freshwater lake								1
	Recreational infrastructure							1	
	Total	**20**	**1**	**14**	**8**	**14**	**4**	**1**	**8**

The reported implementation costs are summarized in Figure 18 and cover mostly the capital expenditure (CAPEX), including construction, planning, land price and legal affairs related to the NbS, CbS and grey solutions implemented at the Demonstration Sites.

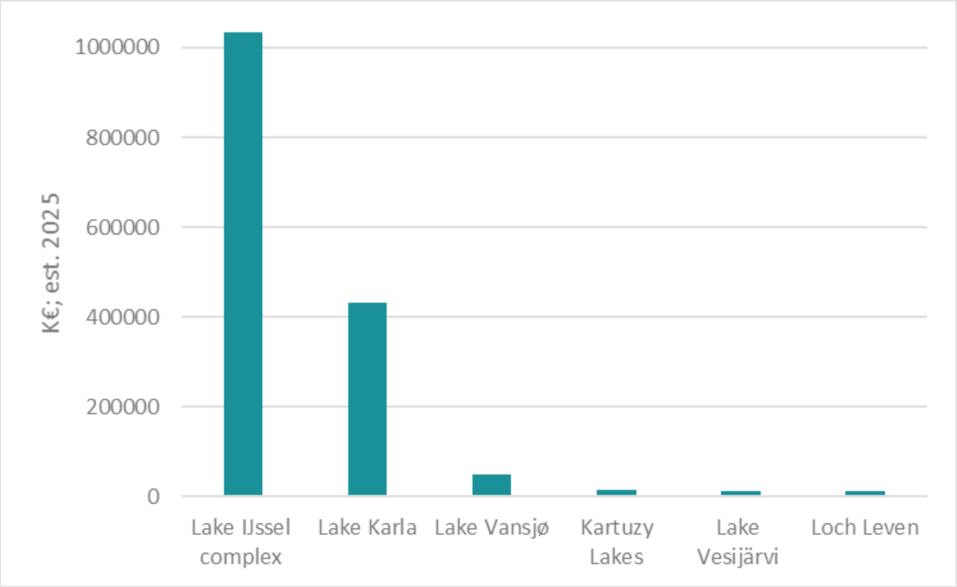


Figure 18: Estimation of the total implementation costs of the restoration measures per Demonstration Site (in thousands of euros, K€)

The Lake IJssel complex is characterized by relatively high costs (more than 1 billion €) covering NbS and BfS measures taken in-lake or along the shoreline, sometimes in combination with flood protection structures, implemented since 1989 and for which records were publicly available. The most important costs items are the natural foreshores created in tandem with dyke renewal (K€786900), the nature islands Marker Wadden (K€96 300), and the fish migration river structure (K€67000). The total implementation costs of restoration measures implemented in **Lake Karla** are around K€ 432 663. This estimation covers the period 2002–2020 and measures such as artificial wetlands (K€ 41 040), artificial islets (K€ 202 851), tourism infrastructure (K€14310) as well as water transportation and irrigation projects (K€ 68 644). We note that the **Kartuzy Lakes and Loch Leven** show relatively low implementation costs. This is mainly explained by the short costing period (3 to 4 years) as well as the lack of records. In the **Loch Leven** case, the expenditures are mainly associated with the sewage treatment measures, including the tertiary treatments (ranging between K€67 and K€225), establishment of a WWTP (K€ 7 700) and the redirection of the WWTP effluent (K€ 3 100). The total implementation expenditure at the **Kartuzy Lakes** is due to sediment removal and the creation of recreational infrastructure, of a total value of K€ 11 000 and 2 326, respectively. The reported CAPEX of **Lake Vansjø** is around 50273,1 K€ and cover the time-period 1999-2012. They include the costs associated with different restoration solutions, such as agricultural measures (14 222 K€), establishment and restoration of riparian zones (220K€) and addition to the sewage treatment (35825 K€). Similarly, the estimated implementation costs in **Lake Vesijärvi** covers a limited number of costs reported between the 1970s and 2017. These include the establishment costs of the wastewater treatment facilities (8 500 K€), biomanipulation (K€ 67.4), aeration (K€ 560) as well as establishment of sedimentation ponds and wetlands (K€ 520). Overall, the total CAPEX are estimated around 11 227 K€ and include the costs of implementing the wastewater treatment plant (K€ 8 500) in addition to total

Funded by
the European Union

costs of two major restoration programmes, namely Vesijärvi “project I” and “project I”, accounting for K€ 2 300 and K€ 1 580, respectively.

3.5.2 Benefits of restoration

Table 15 summarises the total economic streams considered for restored lakes reported in Table A.2, covering non-market and market-based benefits. The breakdown of these benefits into provision, regulation, and cultural services is illustrated in **Error! Reference source not found.**. The valuation covers the revenues and cost-saving streams generated by the restoration measures and programmes.

Table 15. Summary of the economic valuation of the benefits generated per Demonstration Site.

Demonstration Site	Annual Benefits in K€ (est. 2025)	Evaluation period	Evaluated benefits
Lake Vesijärvi	1 836 181,3	2004 - 2025	Recreational fishing, Fisheries, Water quality improvement, farmers revenues' increase, decreased P loading, groundwater abstraction, recreational activities (boating, bathing, ice skating), increased value of built land around the lake
Kartuzy Lakes	148 970	2019-2025	Recreational activities (SUP paddle) during summer, recycling the removed sediment for P reuse, job creation
Lake IJssel complex	4 380	2022-2025	Fisheries, in-lake wind energy production, carbon sequestration
Lake Karla	6 063,4	2025-2026	Irrigation water, drinking water supply, fisheries, recreational activities, job creation
Loch Leven	8608,2	1995-2024	Fisheries, water view, revenue increase of local businesses, reduction of phosphorus (P entering), algal blooms reduction
Lake Vansjø	143 550	2025	Drinking water, irrigation water, recreational activities (boating, bathing, ice skating, fishing)

The economic benefits estimation in **Lake Vesijärvi** covers indirect benefits such as the CAP subsidies for farmers to maintain wetlands, as well as direct regulating services (i.e. water quality improvement, decreased P loading), and other provisioning services (fisheries, groundwater abstraction, recreation, value of estates around the lake shorelines). **Lake Vesijärvi** demonstrates that combined measures for restoration can deliver substantial annual economic value of up to 1.8 billion €. We note that the provisioning services account for more than 99% of the net yearly benefits of the lake, wheareas cultural services are less than 0.3%. However, the value of several recreational activities, such as boating, bathing, tracking, time spent at summer houses around the lake etc. could not be estimated due to lack of data, and we highlight that the value of cultural services is probably higher than represented here.

Kartuzy Lakes shows total annual benefits of 149 million €, with provisioning services (K€148 800) accounting for the entire value (>99%), whereas cultural (K€4) and indirect job creation associated with the restoration programmes (K€166) remains negligible. The economic valuation of the polish demo case is narrowly defined around direct use values and was based on observable market transactions to monetise the provisioning (recycling the removed sediment for P reuse) and cultural (SUP paddle boarding during summer) services. The marginal representation of additional cultural and regulating services is explained by the absence of non-market valuation methods.

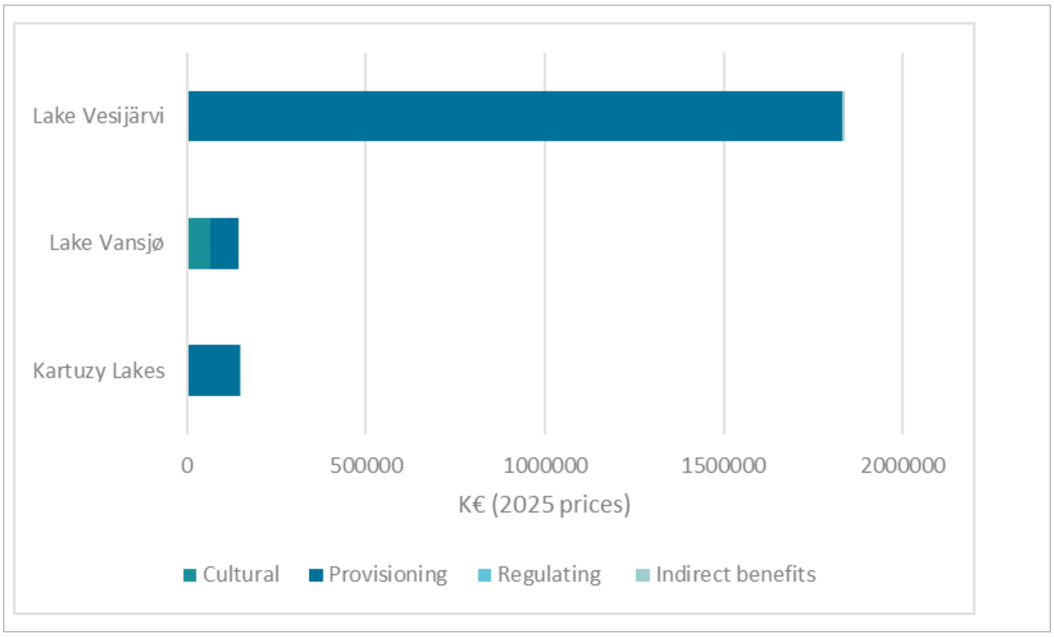
The benefit assessment for the **Lake IJssel complex** covers a relatively narrow subset of direct ecosystem services for which data are known, specifically two provisioning services (i.e. commercial fisheries and in-lake wind energy production) and one regulating service, carbon sequestration. The total estimated annual economic value generated within the **Lake IJssel complex** is valued at 4.4 million €. Provisioning services constitute the dominant share of this value, accounting for approximately 99% of total quantified benefits. In contrast, the monetary valuation of the regulating service is comparatively modest, estimated at approximately €32.6 thousand per year.

Lake Karla has also recorded similar annual benefits estimated at more than 6 million €/year. The valuation includes three provisioning services (namely irrigation water, drinking water supply and fisheries), recreational activities and local job creation. The value structure is strongly dominated by provisioning services (92%) to the generated benefits, followed by the indirect job creation (6%) and cultural services (2%), while regulating services are not reported.

Loch Leven generates 8,6 million € annually and exhibits the most balanced value composition among the lakes assessed. Cultural services i.e. water view (K€3900) represent a substantial share of 45%, followed by regulating services (K€2766), provisioning services i.e. fisheries (K€592), and indirect benefits (K€1350) associated with revenue increase of local businesses. Unlike most other sites, Loch Leven's valuation structure is diversified and less dominated by provisioning services. The relatively high share of cultural and regulating benefits suggests active recreational use and recognition of ecosystem regulation functions such as algal bloom reduction and water purification.

The total benefits recorded by the restored **Lake Vansjø** are estimated around 143,5 million €/year. The valuation is based on the provisioning services (53% of the total value), namely drinking and irrigation water, as well as recreational activities (47%) associated with the lake. This near parity between cultural and provisioning services indicates a multifunctional lake system with strong recreational or amenity-based value alongside productive uses.

This analysis highlights a strong cross-site heterogeneity, reflecting ecological, socio-economic, and methodological differences. The results also show a strong dominance of market-based provisioning services in total monetized value and an underrepresentation of regulating services relative to their likely ecological importance.



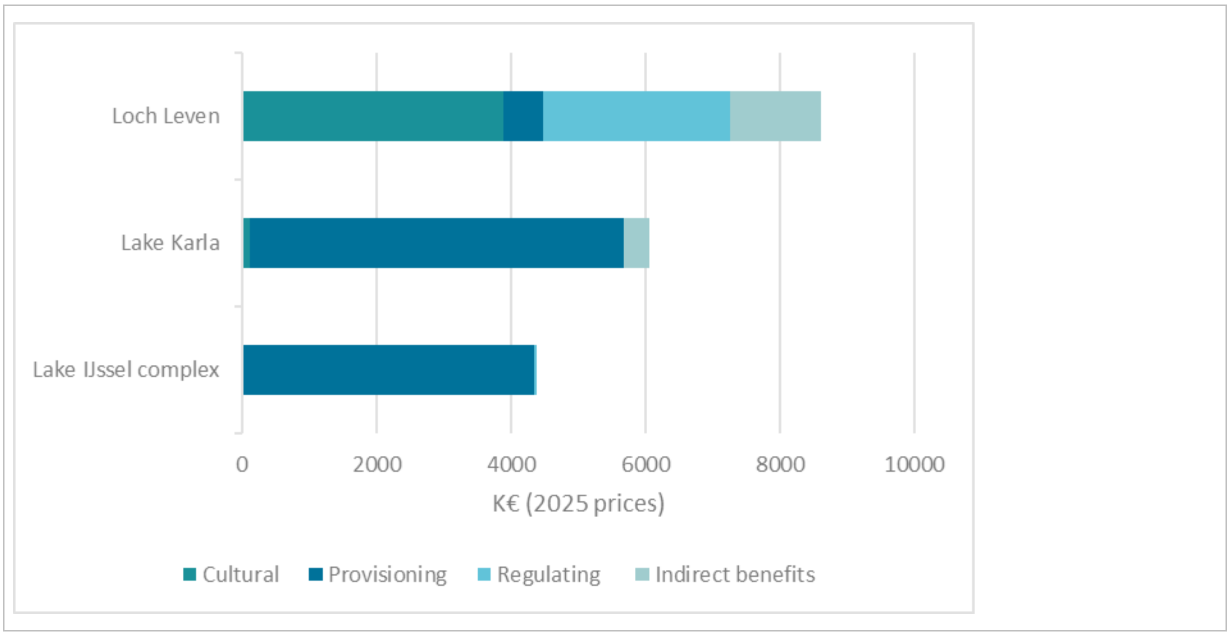


Figure 19: Estimation of annual direct and indirect economic outcomes in thousands of euros (K€), by type of ecosystem services and by Demonstration Site.

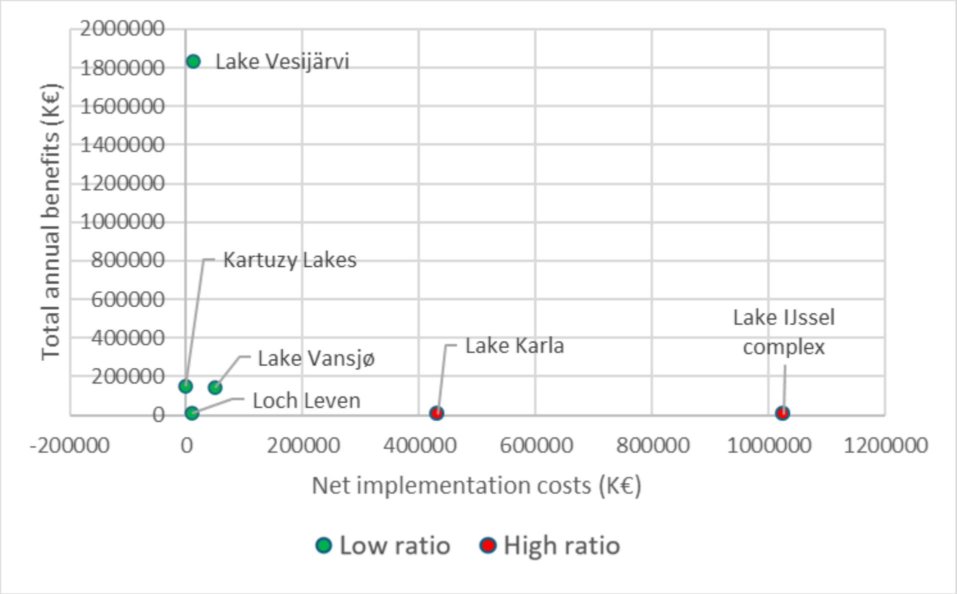


Figure 20: Cost-to-benefit ratios of the Demonstration Sites.

Funded by the European Union

4 Discussion on effectiveness of lake restoration

Successful lake restoration requires a sound understanding of how both large-scale drivers (e.g. climate change) and more local pressures (e.g. land-use) control a lake's water quality, biological structure and ecosystem functioning. At a local catchment scale, factors like hydrological cycles, weather events, and external loading are relevant. In addition, physical aspects of the lake and in-lake processes, such as food web structure, contribute to determining the final status of the lake.

Although the common goals of most lake restoration programmes are achieving sufficient water quantity, good water quality and ecological improvement, the dominant pressures and specific restoration goals vary from lake to lake. In this synthesis we have collected information on six Demonstration Sites across Europe with the aim to understand the impacts of measures, associated scales (time and space) and costs of the restoration efforts better. We have evaluated restoration programmes in terms of water quality and biodiversity, factors that are commonly taken into account when looking at the impacts of lake restoration efforts. In addition, we have included impacts on climate regulation, climate resilience and societal factors like health and well-being, inclusivity and recreation (**Error! Reference source not found.**). Through this, we have evaluated the costs and benefits of restoration programmes.

4.1 Cost-benefit analysis

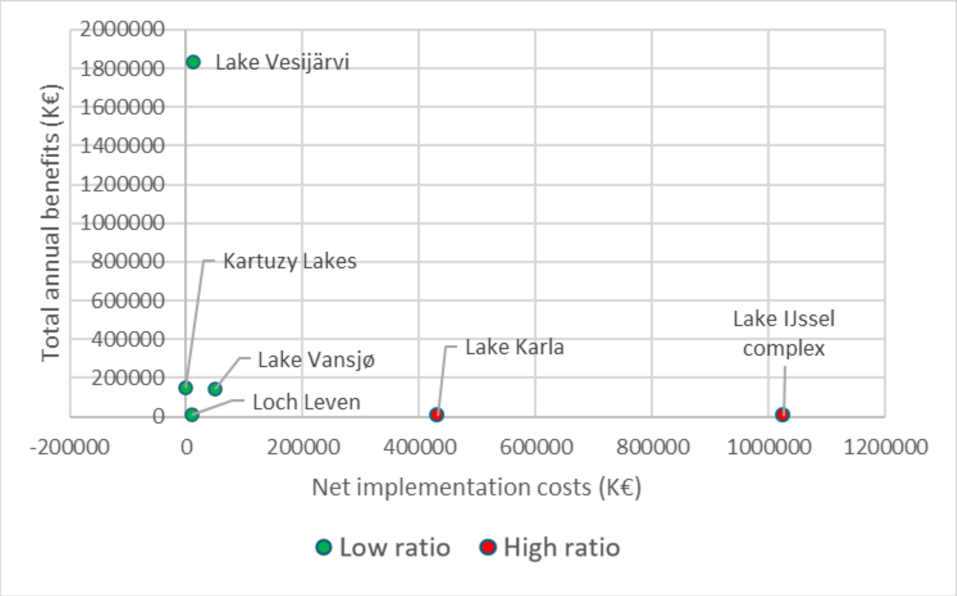


Figure 21: Cost-to-benefit ratios of the Demonstration Sites.

A comparison of the estimated net implementation costs and the annual benefits across the six Demonstration Sites show a wide variety in cost-to- benefit ratios (Figure 21). The cost-to-benefit ratio of each lake is calculated by dividing the net restoration costs by the total expected annual benefits. This ratio represents the payback period in years, i.e. the number of years required for the annual benefits to recover the initial net investment.

Net implementation costs (in K€; est. 2025) represent the difference between the total implementation costs and the total funding and financing received for the restoration programmes. As reported in Table 16, financing in all lake basins has largely been covered by public funds in addition to some private (Lake **Loch Leven**) and blended (**Lake Vansjø** and **Lake Vesijärvi**) financing schemes.

While costs may vary widely, annual benefits exceed costs by a substantial margin in Lake **Vesijärvi, Lake Vansjø, Loch Leven** and **Kartuzy Lakes**, highlighting the strong economic viability for implementing lakes restoration measures. **Lake Vesijärvi** demonstrates (Figure 21) exceptionally low cost-benefit ratio of 0,006 meaning that the initial restoration investment is recovered in less than one year**. Lake Vansjø** has also recorded a low cost-to-benefit ratio (0,35) due to relatively balanced net implementation costs (K€50273,1) and generated economic benefits (K€143550). On the other hand, the negative implementation cost recorded by **Kartuzy Lakes** indicates net funding surplus in addition to a significant monetary benefit. **Loch Leven** shows relatively low annual benefits (K€8608,2) compared to the estimated net implementation costs (K€10448). The cost-benefit ratio is around 1,2 suggesting that the initial investment (implementation costs) is recovered in about 1.2 years through the benefits generated by the restored lakes (excluding any yearly operational costs).

Table 16. Funding and financing schemes of FutureLakes Demonstration Lakes

Lake	Country	Funding (K€; est. 2025)	Years	Source of funding
Lake Vesijärvi	Finland	n.d.	Since 2007	Ministry of the Environment, Ministry of Agriculture and Forestry, EU, Leader Finland, blended finance (municipalities, private companies)
Kartuzy Lakes	Poland	15 700	2019-2023	Operational Programme Infrastructure and Environment 2014-2020 (EU)
Lake IJssel complex	The Netherlands	8 500,60	Since 2000	Regional, national, EU funding (Natura2000)
Lake Karla	Greece	604	Since 1997	ERDF, National Programme of Rural Development (CAP)
Loch Leven	UK	644	Since 2013	Government, United Distillers under the Guiness PLC "Water of Life Scheme"
Lake Vansjø	Norway	n.d.	Since 2004	Ministry of the Environment, Ministry of agriculture, blended finance (local municipalities and landowners)

On the other hand, both **Lake Karla** and **Lake IJssel complex** show high cost-to-benefit ratio according to Figure 21. Lake Karla shows significantly low annual benefits (K€ 6063,4) compared to the implementation costs (K€ 432 663), suggesting low economic return of the restoration measures. In **Lake IJssel complex** the benefits are incomplete, but the available estimates do show the importance of the lake for the region. Furthermore, although the costs for restoration seem substantial in the **Lake**

IJssel complex (K€1025799,4) they are a fraction of the costs of water infrastructure measures taken in the same area.

From the economic benefits perspective (section 3.5.2), the results suggest that the estimated benefits primarily capture direct, marketable ecosystem services, while broader welfare contributions - especially regulating and non-market cultural services - are likely underrepresented in most demonstration cases. Consequently, the reported total annual benefits likely represent conservative estimates of the full social value generated by these lake ecosystems. The absence of regulating service values likely reflects limited scope in regulating service assessment rather than ecological insignificance. The relatively small cultural outcomes could be explained by the limited recreational activities (**Lake Karla, Kartuzy Lakes**) or limited data and amenity valuation (e.g. **Lake IJssel complex**).

The current EU market and institutional structures fail to economically value freshwater ecosystems (in particular lakes), thus contributing to their over-exploitation and generating substantial social and economic costs. This analysis is a valuable support for upcoming policies such as the EU Nature Credits Roadmap as well as the Carbon Removals and Carbon Farming Regulation.

The available data did not allow separate estimation of the capital and operational expenditures. Therefore, we note that this cost analysis is only based on the implementation costs and does not account for the yearly operational expenditures. We note that the costs associated with restoration measures are highly context-dependent and consequently difficult to standardize. In several cases, the cost-benefit analysis was further constrained by the limited availability of data on indirect and direct benefits, explaining the relatively low value of annual benefits (e.g., **Lake Karla** and **Lake IJssel complex**). Lake practitioners should systematically monitor costs to support informed, adaptive, and sustainable decision-making. Coupling cost monitoring with assessments of economic impacts would enable practitioners and policymakers to better evaluate the relative cost-effectiveness of lakes restoration to demonstrate the benefits of restoration, adapt future restoration programmes and ensure efficient allocation of, often public, restoration funds.

4.2 Environmental

Most monitoring data were found for the environmental criteria. Therefore, for these indicators we were able to compare the different lakes. The recovery times against specific individual measures are not evaluated in this study, as many measures have been undertaken, some simultaneously, making it near-impossible to evaluate the outcomes of individual measures, which can take many years to take effect. Rather we focus here on an evaluation of the restoration programmes as a whole, across many years or decades.

4.2.1 WFD chemical and ecological status

All six Demonstration Sites that were part of this project currently fall under the Water Framework Directive. However, not all improvements can be attributed to the restoration programmes established under WFD Programme of Measures (PoM), as the WFD was established in 2000 and restoration efforts for a subset of the lakes were initiated much earlier. In Loch Leven, Lake Vesijärvi, Lake Vansjø and the Lake IJssel complex restoration efforts were already being taken, mainly in the catchment, since the late 1970s or early 1980s, due to issues associated with eutrophication (e.g., toxic algal blooms, fish kills) heavily impacting the water quality and recreational value of these lakes. These restoration efforts were likely also stimulated by the Urban Waste Water Treatment Directive that was established in 1991.

In contrast, the restoration programme at Lake Karla had only just started in 2000 and the restored lake came under the WFD later, while the Kartuzy Lakes did not enter into a restoration programme until 2019, mainly due to local municipal goals to restore the lake for recreational use. Subsequently, the availability of WFD status reports differs per Demonstration Site (Table 2 and Table 3).

WFD chemical status data does not show any improvements for the lakes reporting data that were part of the WFD the longest (Loch Leven, Lake IJssel complex, Lake Vansjø) and that also have had the longest track records of restoration efforts. Conversely, only Lake Karla and two sub-basins from the Kartuzy Lakes have achieved Good chemical status in recent years. Part of the issue for the lack of improvement for many lakes might be found in the strictness of the WFD that takes a one-out-all-out approach. This means that even though there might be substantial improvements for certain substances, this will not be reflected in the final status: that will remain a "failing" as long as just one substance is above its defined threshold. Additionally, a number of substances have been added to the list of priority substances in 2013 and thresholds have become stricter over the years. At the same time, it might be difficult to resolve legacy pollution of certain remaining substances, e.g., even though certain substances such as pesticides and PFOS have been forbidden, they remain present in the system due to their persistent nature.

A similar story can be found in the WFD Ecological status for all of the lakes. In fact, only Loch Leven, Lake Vesijärvi basin 2 and two basins from the Kartuzy Lakes (n.b. these are the same two lakes that show an improved chemical status) currently show improvements of their ecological status class. All other basins in the six Demonstration Sites show no improvement in status class (Lake Vansjø, Lake IJssel in the Lake IJssel complex), or sometimes even a worsening status (Lake Marken in the Lake IJssel complex). The reasons underlying the failure vary from high nutrient and Chl *a* concentrations (Lake Vansjø, Lake Vesijärvi, Lake IJssel complex, Kartuzy Lakes, Loch Leven), but also inadequate migration options for fish and lack of shallow land-water transitions (Lake IJssel complex). The one-out-all-out principle makes achieving good ecological status difficult, even when supporting water quality or individual component biological quality elements have improved. For instance, Lake Vesijärvi basin 2 is at risk of falling back to *Moderate* ecological status despite the low nutrient and Chl *a* concentrations. In this case, the one out determinant is the abundant fish stock that continues to indicate worse than good ecological status, even though biomanipulation has successfully rebalanced the structure of fish communities and the abundance of piscivorous fish stock is high (Ruuhijärvi et al. 2023, DS-Annex a).

Another factor that is likely to play a role in some cases is that in response to restoration, degraded systems may also have resistance and negative resilience to remain in a degraded state (Carpenter et al. 2001, Lake 2012). Because of this, shifts between trophic state are often hard to obtain and require long-term commitment to reduce pollution pressures and sets of "disruptive" perturbations, such as biomanipulation, to break down the resilience of turbid, eutrophic states. Such negative resistance is likely e.g., in Lake Vesijärvi, where epilimnetic nutrient levels have experienced a long-term gradual decline after the sewage diversion in 1976 and sets of restorative measures taken since the late 1980s. Despite these actions, however, the internal P flux from deeper reactive sediment layers is slowing down the full recovery of the lake (Jilbert et al. 2020).

In general, it seems that the longer time series, especially for the lakes with a long restoration history, start with a sharp improvement, while the post-WFD trend is improving slower. Indeed, this is the case for Lake Vesijärvi, where the most pronounced declines in epilimnetic nutrient and Chl *a* concentrations occurred after the sewage treatment in 1976 and onset of consistent biomanipulation in 1989 (e.g., Horppila et al. 1998; Salonen et al. 2020; Salonen et al. 2023). Ever since, multiple measures have been taken to further reduce the nutrient inputs. While the gradual recovery of the lake was initiated before the enactment of WFD in 2000, this regulation leverages the continuum of implementing restoration measures to date. Similarly, in Loch Leven, the main restoration measures were taken before the enactment of WFD and the general long-term trends of P and Chl *a* have been declining. Despite these declines, however, the values have mainly remained within the same WFD status class, demonstrating the importance of evaluating time series data in detail in order to not underestimate the impacts of restoration.

The "resilience" of overall ecological status to improve is masking real improvements in individual water quality or biological indicators, that were the original target of the restoration programmes, such as phosphorus concentrations or levels of algal biomass. The effectiveness of the restoration is, therefore, more important to consider under these specific indicators – as is discussed in the following sections.

4.2.2 Nutrients

Due to the close relationship between nutrient concentrations and (external) nutrient loadings we discuss these two elements in tandem.

The primary goal of restoration in many of the FutureLakes Demonstration Sites, like elsewhere, was to improve water quality by first reducing nutrient concentrations. Excessive external nutrient loads can originate from diffuse (agricultural rainfall run-off) or point sources (wastewater). An example of a typical point source is domestic or urban sewage that is directed into a lake. Hence, a very important element of lake protection and restoration is constructing wastewater treatment plants and sewage systems with sufficient capacity, and to have tertiary treatment to maximise nutrient removal. Excessive diffuse loads are frequently more difficult to tackle, as they require a catchment approach, e.g., changing land management on agricultural fields.

Reduction of nutrients was predominantly achieved by reducing external point-source and diffuse loads (Kartuzy Lakes, Lake Vesijärvi, Lake IJssel complex, Lake Vansjø, Loch Leven), as well as by application of appropriate in-lake applications to reduce internal loads (Lake Vesijärvi, Kartuzy Lakes) (see details in DS-Annexes a - f). For instance, in Lake Vesijärvi, sewage diversion initiated the recovery of the lake, after which multiple measures taken at the catchment scale and in-lake measures have further reduced nutrient loading. While aeration did not result in anticipated reductions in nutrient concentrations (Salmi et al. 2014; Salonen et al. 2023), large-scale, regular biomanipulation since 1989 has led to reductions in both P concentrations and cyanobacterial blooms (e.g., Horppila et al. 1998; Salonen et al. 2020; Salonen et al. 2023) together with the gradual recovery of zooplankton communities (Anttila et al. 2013). However, the lake still suffers from internal and diffuse external loading slowing down the full recovery of the lake (Jilbert et al. 2020). Indeed, the legacy of pollution present in the lake can significantly delay the ecosystem's response to restoration measures.

Early restoration programmes have focused on reducing external nutrients loads (Lake Vesijärvi, Lake Vansjø, Loch Leven, and the Lake IJssel complex), and this is still a best-practice, before measures to reduce internal loading are carried out. While lost recreational amenities prompted the need for improving sewage treatment at some of the Demonstration Sites already in the 1970-1980s (Lake Vesijärvi, Lake Vansjø), the enactment of the Urban Waste Water Treatment Directive (Council Directive 91/271/EEC of 21 May 1991) has further supported the implementation of measures targeting wastewater-derived pollution reduction. After reducing sewage inflows and implementing proper sewage management, diffuse agricultural emissions have now become the more dominant form of external nutrient load in many cases (Lake Karla, Loch Leven, Lake Vesijärvi, Lake Vansjø, Lake IJssel complex), while diffuse nutrient pollution from urban environments (Kartuzy Lakes, Lake Vesijärvi) and forestry (Lake Vesijärvi) is also a concern that needs addressing. While diffuse sources of pollution are more difficult to control, the observed long-term trends of decreasing external nutrient loads at the Demonstration Sites are, however, encouraging.

A comparison between the reductions of nutrients (3.2.1; DS-Annexes a – f) revealed that the reduction of phosphorus pollution has been the focus on most lakes and has thus been managed more effectively than nitrogen. This is likely due to the fact that nitrogen is a more mobile dissolved nutrient that can take forms and transports easily through air, while phosphorus is transported mainly in particulate form via slower processes in water and soil. Although a reduction of phosphorus concentrations in the water can be an effective measure against phytoplankton blooms, a higher nitrogen level in lake waters can also bring problems with harmful algal bloom control and increased toxicity of blooms (Scott and McCarthy 2010).

Most of the lakes external nutrient loadings are now lower in comparison with historical loadings. Hence, it could be concluded that pollution control measures at the catchment level, driven by legislative process, have been successful at reducing nutrient loads (e.g., Urban Wastewater Treatment Directive, National Plans for Sewage Treatment, Nitrate Directive or earlier national standards for pollutants concentration in the waterbodies). The implementation of these legislative acts have clearly opened the possibility of funding for water protection initiatives (such as wastewater treatment plants construction, catchment measures or full-scale lake restoration).

4.2.3 Phytoplankton

In four of the Demonstration Sites (Lake Vesijärvi, Kartuzy Lakes, Loch Leven, Lake Vansjø) the main goals of restoration were related to eutrophication, including reducing algal (cyanobacterial) blooms. Together with improved water quality and reduced nutrient levels (phosphorus in particular), Chl *a* in these four lakes have successfully declined since the beginning of the restoration periods. Consequently, Chl *a* status in these lakes has improved. However, several lakes are still not in *Good* ecological status for Chl *a* (Lake Vesijärvi basin 1, Loch Leven and Lake Vansjø basin Vanemfjorden), and there are large variations between lakes and fluctuations over time (Figure 5).

The results demonstrate how lake responses can vary considerably in relation to reductions in nutrient levels, with lake characteristics and catchment contexts affecting the Chl *a* response, and it can be difficult to predict the scale and timing of response with simple models. Initially, the implementation of individual lake measures had clear effects on Chl *a* concentrations, mainly following point-source reductions in bioavailable forms of nutrients (also see 4.2.2 Nutrients). However, in Lake Vesijärvi (basin 1), Loch Leven and Lake Vansjø the Chl *a* levels have increased again in recent years, due to other external factors, including increased runoff and erosion from precipitation events, and warmer temperatures. The lack of sustained long-term declines in Chl *a* has reflected changes in phytoplankton communities and emergence of cyanobacteria (Lake Vesijärvi) or algal groups other than cyanobacteria (Lake Vansjø; DS-Annex f). Contradictory to initial expectations, the concentrations of epilimnetic nutrients in Lake Vesijärvi were not affected by hypolimnetic oxygenation despite the disappearance of anoxia (Salmi et al. 2014; Salonen et al. 2023). Instead, oxygenation potentially increased the gas ebullition from sediment with increased nutrient fluxes to the epilimnion, which consequently intensified the cyanobacterial blooms (Salonen et al. 2023; DS-Annex a). However, the fluctuations in the planktivorous fish population have substantially influenced the zooplankton and phytoplankton communities in Lake Vesijärvi, demonstrating the impact of biomanipulation and top-down control (e.g., Ruuhijärvi et al. 2020, Salonen et al. 2023). Loch Leven, in turn, has experienced a comeback of cyanobacterial blooms, possibly related to increased water temperature and release of soluble reactive phosphorus (SRP) from sediments (DS-Annex e). In the Kartuzy Lakes, restoration has only been implemented in recent years, and the concentrations of Chl *a* have so far been successfully reduced in three of the four lakes, showing clear immediate effects from the restoration measures (Figure 5).

Despite the still Moderate status for Chl *a* in Lakes Vesijärvi and Vansjø, restoration measures have been successful in terms of reducing the frequency and extent of toxic cyanobacterial blooms, going from annual blooms with frequent production of toxins, and consequent reduced recreational use of the lake, to only sporadic blooms with several years between with no toxic blooms (DS-Annexes a, f). The same is true for three of the four Kartuzy Lakes, where both Chl *a* and blooms of harmful cyanobacteria have been reduced due to the restoration efforts (DS-Annex b). By contrast, in one Kartuzy Lake (Karczemne) the reduction in nutrients and Chl *a* is significant, but not sufficient in order to reduce cyanobacterial blooms, which are still occurring (DS-Annex b).

In the four lakes with restoration goals related to eutrophication and algal bloom problems, nutrient reductions appear to have limited algal blooms and improved water quality. However, with increased temperatures, precipitation events and flooding, increased external and internal loading of phosphorus is occurring, water colour increasing at Vansjø (browning) and phytoplankton community assemblages are changing in response to these. In Lake Vansjø, climate change in recent decades has led to browning and consequent changes in the algal community composition with emergence of algal groups that contribute to keeping Chl *a* concentrations high (e.g. *Raphidophyta*) even in lower nutrient concentrations (DS-Annex f). Specifically in terms of reduction of cyanobacterial blooms, the restoration in the four Demonstration Sites have been successful, even when not measurable by Chl *a* reductions.

The two other Demonstration Sites, Lake IJssel complex and Lake Karla, were mainly focused on restoring biodiversity and combatting water scarcity, respectively. Even so, Chl *a* levels have declined in the Lake IJssel complex since 2000, due to improved wastewater treatment, improving the lake from mainly *Poor* to *Moderate* status, with certain years also reaching *Good status* (DS-Annex c). Contrary, in Lake Karla, Chl *a* has only been monitored since 2013, and has increased Chl a since 2020; the phytoplankton community consisting of high amounts of cyanobacteria, with some years almost full domination (DS-Annex d).

4.2.4 Biodiversity

Restoring biodiversity was a primary goal only at the Lake IJssel complex Demonstration Site, where restoration focused on creating 8 km^2 of new island habitats to support internationally important bird populations. At Lake Karla the primary goal for restoration was water supply, mainly for agriculture, as well as biodiversity enhancement. The measures successfully restored 34.9 km^2 of open water habitat required by the many bird species that the Special Protection Area was originally designated for. The measures to increase water levels at Lake Karla should also have helped priority fish species that the Special Area of Conservation was, in-part, designated for, by restoring associated wetland and stream habitats used by the fish locally.

Several sites documented positive effects of restoration programmes on biodiversity. Many sites documented an initial loss, or decline, of species of high conservation importance associated with the most severely polluted years before restoration (i.e., Kartuzy Lakes, Loch Leven), or in the case of Lake Karla, drying out of the lake. Recovery of species populations has coincided with improvements in water quantity or quality delivered by the restoration programmes. For example, the return of pollution-sensitive submerged plants at Loch Leven (Dudley et al., 2012) and at the Kartuzy Lakes (Augustyniak pers. comm.).

Changes in highly mobile species, such as birds or migratory fish, can be more difficult to attribute to local changes in habitat extent or quality as there are many contributing factors to changes in their populations. Climate change, for example, results in milder winters (implicated in increasing trends of 2 bird species at Loch Leven). Some bird species changes also reflect broader national trends driven by land-use changes and climate change shifting migration patterns. Populations of some birds (Loch Leven) and dragonfly (Lake Vesijärvi) species, however, show stable or improving trends at the lake level that buck national or European declining trends, indicating local biodiversity benefits from either the protected area status of the lake, or direct responses to the restoration measures. Also successful was the building of the nature islands Marker Wadden in the Lake IJssel complex, that created an increase of available habitats for several Natura 2000 bird species.

Biological pressures, such as invasive non-native species, can further impact lake food webs and native species. Introduction of non-native fish, mollusc and aquatic plant species is common across Europe and this was also true for these sites of conservation importance (examples include Canadian pondweed at many sites, and carp at the Kartuzy Lakes). At Lake Vansjø, continuing declines of bird breeding numbers are thought to be associated with increases in the North American mink in the catchment, a non-native, invasive predator, highlighting the need for restoration programmes to adapt to new challenges. Recovery of some nutrient-sensitive species, such as the slender water-naiad (*Najas flexilis*), may also require further littoral restoration measures, due to habitat loss from shoreline construction and dredging (Lake IJssel complex, Lake Vesijärvi). Hunting and increased recreational boating have also been identified as contributory pressures (Lake Vesijärvi) and, like general recreational pressures around lakes, require careful management to minimise impacts on priority species and habitats. The construction of an all-access “Heritage Trail” around the entire Loch Leven perimeter is a positive example of a recreational infrastructure measure designed carefully with biodiversity in-mind, to manage access to the lake, avoiding key bird nesting and brooding areas, and providing well-managed access through bird hides and viewpoints to encourage public engagement with nature.

Funded by the European Union

In summary, the water quality and quantity focused restoration programmes have delivered significant positive impacts for biodiversity. Further improvements may require a range of different measures, targeting hydro-morphological pressures and invasive species. Habitat creation and well managed recreational access further strengthened lake basin management/restoration programmes. Combined these measures contribute to increased resilience of biodiversity to growing pressures from climate change, urbanisation and visitor pressures.

4.2.5 Zero pollution

Among the six Demonstration Sites the data on heavy metals, microplastics and PFOS concentrations were gathered only (sparsely) for three lakes (Lake Vesijärvi, Lake Vansjø, and the Lake IJssel complex). From these data it is clear that emerging pollutants, such as microplastics and PFAS, are already present at the Demonstration Sites, often in quantities exceeding levels considered hazardous to animal and human health (e.g., Lake Vansjø). Although some data are available, we do conclude that there is a major monitoring gap in the data on these pollutants that are the target of the EU's Zero Pollution action. There is a knowledge gap on the concentrations of substances as well as on the sources that clearly needs addressing.

Legislation in the area of monitoring obligations with regard to emerging contaminants is still under development in the EU (Lewis et al. 2022, Aziz et al. 2023, Rakib et al. 2023). The available data from the Demonstration Sites indicates that the level of pollution can pose a risk to ecosystems and human health, especially if restored lakes are used for food production (fisheries), or as water supply sources. EQS for heavy metals and PFOS were exceeded particularly in the case of Lake Vansjø (DS-Annex f). Taking into consideration the potential harm for public and animal health as well as ecosystem health highlights a strong need for a more integrated One Health approach for monitoring harmful pollutants

An additional concern is that some innovative restoration measures, such as biomanipulation and sediment dredging, can result in new pathways for pollutants outside of the lake. A prime example of good practice in avoiding such risk is the case of sediment dredging in the Kartuzy Lakes (Grochowska et al. 2020, 2021). In this case, a thorough evaluation of the sediment pollution level was made, and that data were used for further sediment treatment development in the Kartuzy WWTP. Similarly in the Lake Ormstrup innovation site, careful testing of the transfer of pollutants in crops is a key aspect of this pilot study site being considered in both EU FutureLakes[1] and FERRO[2] projects.

4.3 Restoration and Climate Change

In regard to restoration efforts and their GHG-emissions, the initial estimations indicate that lake restoration might be an effective way to reduce GHG-emissions (demonstrating a GHG-emission reduction up to 50%; **Error! Reference source not found.**). However, it should be stressed that more work is needed to validate these model results before they can be used confidently in large scale greenhouse gas emission inventories. Additionally, these results suggest that applying a single average emission rate across all lakes (e.g. 1.46 t CO_2-eq/ha/y), irrespective of water quality, as recommended by the IPCC guidance – which was developed for reservoirs - could lead to large errors in the estimation of CH_4-C emissions from lakes. It is clearly important that models to predict emission changes following water quality improvements are validated with monitoring data before they are used in large scale assessments of greenhouse gas emissions. These measured data are becoming available (e.g. at Loch

---

[1] https://futurelakes.eu/innovation-measures/lake-ormstrup-denmark

[2] https://ferroproject.eu/demonstration-sites

Leven and Vesijärvi), but need further support to maintain monitoring and upscaling to other sites in different lake, and climatic contexts.

Water protection and restoration measures have also successfully contributed to creating sponge landscapes, i.e., increased the water retention capacity of some of the basins. For instance, restoration of Lake Karla successfully re-established the natural hydrological functions and, due to the augmented connectivity, an ability to store more water. The restoration programme at this site itself was, in part, framed as a climate adaptation measure, addressing flood resilience following future projections (Tzabiras et al., 2016) and water scarcity (Panagopoulos & Dimitriou 2020) under changing climate conditions in the Mediterranean region. The existence of the reservoir enabled the degraded and nitrogen polluted (Sidiropoulos et al., 2019) aquifer to recharge by 33.2 million m^3 per year, which is almost 30 million m^3 more than the precipitation-based recharge from the same area (Panagopoulos et al., 2023), adding thus an “extra line of defense” for drought resilience. Also, at Lake Vesijärvi and Loch Leven, nature-based water protection structures (e.g., constructed wetlands, green infrastructure) potentially contribute to flood and drought mitigation by increasing the water retention capacity of the catchment areas. Additionally, the water level of both lakes is controlled, potentially providing climate change resilience through adjusting the water volume of the lakes. However, the sluice gate of Loch Leven also results in a failing status under the WFD, by increasing hydromorphological modification and acting as a fish barrier as a trade-off. These trade-offs and conflicts between policies (WFD vs Climate resilience) mean local stakeholder decisions are as important as individual policy goals, to ensure lakes are managed for local community and national needs. The water level of Lake IJssel complex is also being regulated to secure water allocation to the Dutch society and programmes are in place to ensure water security under different climate change scenarios. Also, in Lake Vansjø, possibilities for increasing the lake’s climate resilience by increasing the lake outlet capacity, building a flood tunnel and increasing the erosion control of rivers draining to the lake have been assessed.

So far, limited information is available on the impacts of restoration programmes on the resilience of FutureLakes Demonstration Sites to climate change. Although climate change is partly challenging the success of restoration at FutureLakes Demonstration Sites, the restoration measures have successfully reduced the nutrient concentrations in, for instance Lake IJssel complex, Loch Leven, and Lake Vesijärvi, potentially reducing the risk of cyanobacterial blooms while the temperature of surface waters is increasing. At this point in time there is no conclusive evidence for this statement of increased resilience and should be considered as a working hypothesis. Habitat creation and enhancement also appears to to make lake biodiversity more resilient to climate change (e.g., Lake Karla and Lake IJssel complex).

4.4 Societal impacts of restoration programmes

Comparative analysis of the six Demonstration Sites reveals that lake restoration is a strategic investment rather than a mere environmental expense. Restoration generates societal benefits mainly in the fields of health and recreation. Consequently, while initial costs are often perceived as barriers to implementing measures, restoration projects typically carry high benefit-to-cost ratios (Table 15).

Systems with advanced ecological recovery, such as Loch Leven, Lake IJssel complex, and Lake Vesijärvi, deliver substantial economic and recreational value when supported by integrated governance and infrastructure (Li et al. 2025, Ding et al. 2023, Costanza et al. 2017). Restoring bathing water quality immediately stimulates recreational demand and serves as an opportunity for economic development. When combined with strategic infrastructure, restored lakes act as powerful multipliers, supporting year-round activities, sustained revenue and increased local house prices. Conversely, in early-stage systems like Lake Karla, returns are currently dominated by provisioning services (such as irrigation water), which have economic value, but due to on-going water restrictions, the recreational use remains minimal (Moore et al. 2023, Grizzetti et al. 2019). This suggests that further targeted investment in restoration and infrastructure, could unlock significant recreational and cultural revenues (Kowalczewska-Madura et al. 2022).

Studies show that the availability of accessible, nature-friendly, visitor infrastructure and the development of diverse activities is crucial for recreational development of lake-fronts (Shi et al. 2025, Costanza et al. 2017). With the exception of Lake Karla, all Demonstration Sites have a well-developed infrastructure to access and/or recreate near the lake. A wide range of available and accessible infrastructure expands visitor numbers and the groups that can visit an area of interest (Iannacconne et al. 2024), leading to increased recreational value and generated economic impact.

Beyond direct economic benefits, restoration delivers efficiency through ‘avoided’ costs, such as reducing nutrient loads to downstream coastal regions and decreasing the financial burden of water treatment or mitigating flood risks (Poikane et al. 2024, Reynaud & Lanzanova 2017). Lake restoration also delivers non-monetised societal benefits, such as enhancing physical and mental well-being and fosters community engagement in nature (see paragraph 3.4).

Inclusivity can be seen as both a prerequisite for, and the outcome of, successful lake restoration. The literature consistently frames inclusivity as a foundational requirement: without inclusive stakeholder engagement from the start, restoration projects risk failure due to resistance, poor legitimacy or missed local knowledge. Poor public engagement has been highlighted as one of the main obstacles to effective restoration in the World Water Quality Alliance (WWQA) Global Survey of Lake Restoration Practitioners, with more than half of respondents identifying stakeholder engagement as a decisive factor for project success, ranking it higher than knowledge and available resources (Poikane et al., 2024).

Successful restoration on the other hand can mobilize collaboration, foster inclusivity, build new ways of working together, lead to better communication of lake related knowledge, even create new institutions, as in the Lake Vesijärvi case where a dedicated Vesijärvi Foundation was established in 2007 to foster and coordinate the protection and restoration of the lake. Therefore, lake restoration can significantly strengthen community cohesion and local stewardship. Community mobilisation (lake days, citizen science campaigns, etc.) help build pride and a shared local identity, as residents, schools and businesses assume joint responsibility for the lake. When people are directly involved, they develop a sense of ownership that supports long-term monitoring and protection, encourages behavioral changes, such as better waste management and reduced pollution, and ultimately makes restoration outcomes more durable and effective.

Based on the above-mentioned, restored lake systems can serve as multipliers of social and economic value, as well as pillars of heritage and recreation. Recreational activities generate socio-economic benefits for the local communities (Prasanya et al. 2024; Poulsen et al. 2022). The six cases highlight that the greatest recreational gains occur where ecological restoration is combined with long-term investment in nature-positive, access infrastructure, supportive management, and integration of environmental objectives within leisure and tourism development. However, careful planning and sustainable management is essential, as increasing visitor numbers can increase the impacts of anthropogenic pressures in the restored areas if not managed carefully (Murgante et al. 2023, Venohr et al. 2023, Dynowski et al. 2019, Allan et al. 2015) and, therefore, balancing between these factors remains a challenge.

4.5 Synergies and trade-offs between restoration and economic sectors

Alongside the documented economic benefits of restoration programmes for the recreation and tourism sectors, reported in the results, it is important to recognise that there can be both synergies and trade-offs with other economic sectors. Below a few possible synergy or conflicts are mentioned. However, no quantitative data have been collected to substantiate the mentioned aspects.

The most apparent conflict is between certain restoration efforts and the agricultural sector. The use of artificial fertilizers and manure in agriculture remains a substantial diffuse source of nutrient in many of the case-studies.

Treating sewage has had benefits for health and water quality. The greatest impacts on improving water quality and restoring biodiversity have stemmed from improvements of sewage treatment works and diversion of effluents. These measures, many driven by the Urban Waste Water Directive, were costly for the industry, although costs in most cases should have been recovered through water bills and local taxes.

Lakes can be important for renewable energy production. Many lake outflows are managed to ensure water supply for hydropower production (e.g., downstream of Loch Leven). The Lake IJssel complex has many in-lake wind turbines, that produce enough energy to power almost 800 000 households per year. Although hydropower and wind farms provide a relatively cheap source of renewable energy to regions, they do still have documented conflicts with nature, particularly affecting migratory fish and wetland bird species.

Floating solar installations have not yet been implemented at the six Demonstration Sites. The surfaces of European lakes could be used to generate sustainable energy by placing floating solar panels. The impact of floating solar however will impact the primary production of a freshwater lake (Van Veenendaal et al. submitted). Lakes, including Loch Leven, have been considered as a source of energy through heat pumps, as is operational on Lake Geneva. In summary there are strong synergies in managing lakes for renewable energy production, but environmental impacts need consideration and conflicts with wildlife need to be managed. Plans for using Klasztorne Małe Lake (Kartuzy Lakes) as a heat source for heat pump are also considered (Augustyniak-Tunowska, pers. comm), and preliminary research on this lake are planned in 2026.

5 Conclusions

The analysis across the six Demonstration Sites reveals several overarching lessons that are critical for understanding both the progress made and the challenges that remain in lake restoration. Together, these findings highlight common patterns, systemic gaps and emerging pressures that influence restoration outcomes across Europe. Applying the criteria developed in this study can help to assess both the positive and negative impacts of restoration. The main conclusions are summarised below.

The findings from the six Demonstration Sites underscore the inherent complexity of lake restoration. Successful recovery demands time to show improvements, extensive coordination and the involvement of numerous stakeholders, yet the results show that meaningful improvements are achievable despite these challenges. Across the sites, restoration measures have been implemented and have already produced clear environmental benefits.

In many Demonstration Sites, restoration efforts were initially driven by legislative obligations, particularly the Urban Waste Water Treatment Directive (UWWD), the Water Framework Directive (WFD) and the Natura 2000 (N2000) directives. Maintaining these improvements requires continued protection of the restored systems. Local engagement has also proven essential for a robust success. Examples such as Lake Vesijärvi, Loch Leven and the Kartuzy Lakes illustrate how stakeholder cooperation and public pressure can effectively stimulate and sustain restoration progress.

Because lake ecosystems respond slowly, the results of restoration are often visible only after many years. This highlights the need for robust, consistent and long-term dataset to track changes and evaluate programme outcomes. The comparison across sites reveals two major gaps in current monitoring practices. First, there is a lack of data on the economic and societal costs and benefits of restoration. Information on restoration expenditures is often sparse or hidden in grey literature, while data on societal gains—such as increased recreation, rising property values or benefits to local stakeholders—remain limited. Second, quantitative information on greenhouse gas emissions and carbon storage associated with restoration measures is largely missing.

This evaluation also demonstrates the importance of assessing restoration at broader spatial scales. While some benefits may not be immediately visible at the local level, they can emerge more clearly at regional or national scales. For example, in-lake measure can strengthen regional tourism or support national Natura 2000 conservation targets.

A wide variety of restoration measures have been applied across the Demonstration Sites (Table 5; DS-Annexes a – f), and many ecosystems have shown signs of recovery. However, linking specific measures to specific outcomes remains challenging due to the complexity of interacting pressures and interventions. Long-term nutrient datasets—particularly total P concentrations for Lake Vesijärvi, Lake Vansjø, Lake IJssel complex and Loch Leven—show declining trends that began even before the WFD was introduced, indicating that earlier policy frameworks such as the UWWTD (1991) already played a role in improving water quality.

Despite the progress we have observed in improving water quality and reducing harmful algal blooms, none of the Demonstration Sites have yet achieved the over-arching WFD target for good status. Although clear ecological improvements have occurred, these gains are not reflected in the formal WFD status assessment, partly due to the one-out-all-out principle, which masks improvements visible in individual parameters. Achieving the remaining targets is made more difficult by the fact that earlier, easier measures (such as tackling point-source pollution) have already been implemented, leaving more complex issues, such as diffuse agricultural pollution and atmospheric deposition, to be addressed.

Climate change adds an additional layer of complexity. Rising temperatures may counteract improvements in phytoplankton biomass achieved through nutrient reductions, as observed in Lake Vansjø and Loch Leven. Shifts in species distributions toward higher latitudes further complicates WFD ecological assessments, which rely on the presence of specific indicator species. These climate-related uncertainties, together with emerging pollutants such as microplastics and new chemical compounds, highlight the need for restoration programmes to remain flexible and adaptive. Meanwhile, the WFD list of hazardous substances has become outdated, limiting its ability to capture the impacts of emerging contaminants entering aquatic ecosystems.

Another structural gap in monitoring concerns lake size. Under current EU practice, only lakes larger than 50 ha are included in national monitoring programmes. As a result, many small but ecologically important lakes—such as some of the Kartuzy Lakes—are excluded. This omission increases the cost and effort required during restoration planning, as baseline data on trophic status, pollution levels and historical impacts are often lacking for these smaller systems.

6 Acknowledgements

FutureLakes is funded by the European Union through a Horizon Europe Innovation Action under Grant Agreement Number 101156425. UKCEH is funded by UK Research and Innovation (UKRI). The project contributes to the Mission Restore our Ocean & Waters.

We dedicate this work to the memory of Ismo Malin, whose contributions to the protection and restoration of Lake Vesijärvi remain deeply valued. In addition to him, we kindly acknowledge Joonas Rajala and Juhani Järveläinen from the City of Lahti, Heikki Mäkinen, Mirva Ketola and Anna Hakala from the Lake Vesijärvi Foundation, Kirsi Kuoppamäki from the University of Helsinki, Tapio Kilponen from

Lahti Aqua, Anniina Jäntti, Frida Sulalampi and Kalle Vaimala from the municipality of Asikkala, Riikka Johansson from the municipality of Hollola, and Heini-Marja Hulkko, Riitta Ryömä, Hannu Sillanpää and Petri Horppila from the regional Centre for Economic Development, Transport and the Environment for providing invaluable support in collecting data and collating information on the impacts of Vesijärvi restoration programme.

We kindly acknowledge Carina Rossebø Isdahl from the Morsa organisation and Peter Sjolte Ranke from BirdLife Norway for their valuable input and feedback on the Lake Vansjø (DS-Annex f), and Birger Skjelbred, Bernhard Askedalen and Sigrid Haande from NIVA for collection and presentation of data.

We kindly acknowledge Ruurd Noordhuis and Jesse van Leeuwen from Deltares, Marcel van den Berg from Rijkswaterstaat and Gerben Kalkman from Coalitie Het Blauwe Hart Natuurlijk for their valuable input and feedback on the Lake IJssel complex (DS-Annex c).

7 References

Abell, J.M., Özkundakci, D., Hamilton, D.P., Reeves, P., 2022. Restoring shallow lakes impaired by eutrophication: Approaches, outcomes, and challenges. Critical Reviews in Environmental Science and Technology 52, 1199–1246. https://doi.org/10.1080/10643389.2020.1854564

Adrian, R., O'Reilly, C.M., Zagarese, H., Baines, S.B., Hessen, D.O., Keller, W., Livingstone, D.M., Sommaruga, R., Straile, D., Van Donk, E., Weyhenmeyer, G.A., Winder, M., 2009. Lakes as sentinels of climate change. Limnol. & Oceanog. 54, 2283–2297. https://doi.org/10.4319/lo.2009.54.6_part_2.2283

Allan, J. D., Smith, S. D., McIntyre, P. B., Joseph, C. A., Dickinson, C. E., Marino, A. L., Biel, R.G., Olson, J.C., Doran, P.J., Rutherford, E.S., Adkins, J.E. and Adeyemo, A. O., 2015. Using cultural ecosystem services to inform restoration priorities in the Laurentian Great Lakes. Frontiers in Ecology and the Environment, 13(8), 418-424. https://doi.org/10.1890/140328

Anttila, S., M. Ketola, K. Kuoppamäki & T. Kairesalo, 2013. Identification of a biomanipulation-driven regime shift in Lake Vesijärvi: Implications for lake management. Freshwater Biology 58(7):1494-1502 doi:10.1111/fwb.12150.

Artsobservasjoner.no; Artskart. Norwegian Biodiversity Information Centre. Accessed 13.10.2025.

Aziz, K.H.H., Mustafa, F.S., Omer, K.O. Heavy metal pollution in the aquatic environment efficient and low-cost removal approaches to eliminate their toxicity: a review. RSC Advances 2023, 26, https://doi.org/10.1039/d3ra00723e

Baren, S.A. van, Arets, E.J.M.M., Erkens, G., Kramer, H., Lesschen, J.P., Schelhaas, M.J. 2025. Greenhouse gas reporting of the LULUCF sector in the Netherlands. WOT-technical report 278. Wageningen University & Research.

Burden, D.G., Malone, R.F., Mericas, C.E. 1986. A stochastic adaptaion of the Vollenweider phosphorus model. *Lake and Reservoir Management* 2:1, 149-153, https://doi.org/10.1080-07438148609354618

Carpenter, S., Walker, B., Anderies, J.M. & Abel, N. 2001. From metaphor to measurement: Resilience of what to what? Ecosystems, 4 (8): 765-781. https://doi.org/10.1007/s10021-001-0045-9

Carss, D., Spears, B. M., Quinn, L. & Cooper, R. 2012. Long-term variations in waterfowl populations in Loch Leven: identifying discontinuities between local and national trends. Hydrobiologia, 681, 85-104. https://doi.org/10.1007/s10750-011-0927-6.

Carvalho et al. 2024. MERLIN Deliverable D1.2 Monitoring the impact of freshwater and wetland restoration on the European Green Deal goals. Updated Version 11/2024, accessed on 08.01.2026 at https://project-merlin.eu/deliverables/articles/deliverable-d1-2.html

Carvalho, L.; Mackay, E.B.; Cardoso, A.C.; Baattrup-Pedersen, A.; Birk, S.; Blackstock, K.L.; Borics, G.; Borja, A.; Feld, C.K.; Ferreira, M.T. Ferreira, M.T. Globevnik L., Grizzetti B., Hendry S., Hering D., Kelly M., Langaas S., Meissner K., Panagopoulos Y., Penning E., Rouillard J., Sabater S., Schmedtje U., Spears B.M., Venohr M., van de Bund W., Lyche Solheim A., 2019. Protecting and restoring Europe's waters: An analysis of the future development needs of the Water Framework Directive. Science of the Total Environment, 658, 1228-1238. www.doi.org/10.1016/j.scitotenv.2018.12.255

CBS. 2025, 20 Feb. Economische gebruikswaarde natuur in tien jaar tijd met de helft gegroeid.

Cichoń, M., 2019. Valuation of lake ecosystems of Central Pomerania by young people using the contingent valuation method: use of the beach and the swimming area. Economics and Environment, 70(3), p.10.

Costanza, R., d’Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O’Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt, M., 1997. The value of the world’s ecosystem services and natural capital. Nature. 387(6630), pp.253–260. Available from: https://doi.org/10.1038/387253a0

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S. and Grasso, M., 2017. Twenty years of ecosystem services: How far have we come and how far do we still need to go? Ecosystem Services 28, 1–16. https://doi.org/10.1016/j.ecoser.2017.09.008

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P. and van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services, 1(1), pp.50–61.

DelSontro, T., Beaulieu, J.J. and Downing, J.A. (2018), Greenhouse gas emissions from lakes and impoundments: Upscaling in the face of global change. Limnol Oceanogr Lett, 3: 64-75. https://doi.org/10.1002/lol2.10073.

Ding, Z., Zheng, H., Wang, J., O'Connor, P., Li, C., Chen, X., Li, R. and Ouyang, Z., 2023. Integrating top-down and bottom-up approaches improves practicality and efficiency of large-scale ecological restoration planning: Insights from a social–ecological system. Engineering, 31, 50-58. https://doi.org/10.1016/j.eng.2022.08.008

Dudley, B., Gunn, I. D. M., Carvalho, L., Proctor, I., O'Hare, M. T., Murphy, K. J. & Milligan, A. 2012. ‘Changes in aquatic macrophyte communities in Loch Leven: evidence of recovery from eutrophication?’ Hydrobiologia, 681, 49-57. https://doi.org/10.1007/s10750-011-0924-9.

Dynowski, P., Senetra, A., Źróbek-Sokolnik, A. and Kozłowski, J., 2019. The impact of recreational activities on aquatic vegetation in alpine lakes. Water, 11(1), 173. https://doi.org/10.3390/w11010173

European Commission, 2021. *Evaluating the Impact of Nature-based Solutions: A Handbook for Practitioners*. Dumitru A. and Wendling L. (Eds.), March 2021. doi:10.2777/244577.

European Environment Agency, 2024. Europe's state of water 2024. EEA Report 07/2024. doi: 10.2800/02236

European Environment Agency, 2025. Eutrophication caused by atmospheric nitrogen deposition in Europe. https://www.eea.europa.eu/en/analysis/indicators/eutrophication-caused-by-atmospheric-nitrogen?activeAccordion=309c5ef9-de09-4759-bc02-802370dfa366. (access 10.01.2026).

Fenocchi, A., Pella, N., Copetti, D., Buzzi, F., Mogni, D., Salmaso, N., Dresti C., 2025. Use of process-based coupled ecological-hydrodynamic models to support lake water ecosystem service protection planning at the regional scale. *Journal of Contaminant Hydrology* 268, 104469, https://doi.org/10.1016/j.conhyd.2024.104469

Frenken, T., Brandenburg, K.M., Van de Waal, D.B., 2023. Long-term nutrient load reductions and increasing lake TN : TP stoichiometry decrease phytoplankton biomass and diversity in a large shallow lake. Limnology and Oceanography 68, 2389–2401. https://doi.org/10.1002/lno.12428

Gann GD, McDonald T, Walder B, Aronson J, Nelson CR, Jonson J, Hallett JG, Eisenberg C, Guariguata MR, Liu J, Hua F, Echeverría C, Gonzales E, Shaw N, Decleer K, Dixon KW, 2019. International principles and standards for the practice of ecological restoration. Second edition. Restoration Ecology 27(S1): S1–S46.

Grizzetti, B., Liquete, C., Pistocchi, A., Vigiak, O., Zulian, G., Bouraoui, F., de Roo A. and Cardoso, A. C., 2019. Relationship between ecological condition and ecosystem services in European rivers, lakes and coastal waters. Science of the Total Environment, 671, 452-465. https://doi.org/10.1016/j.scitotenv.2019.03.155

Grochowska J., 2015 The cycling of selected macroelements and nutrients in the river-lake system on the example of upper course of Pasłęka River. Monographs of Environmental Engineering, PAS, Lublin 2015.

Grochowska, J., Augustyniak, R., Łopata, M., Tandyrak, R., 2020, Is it possible to restore a heavily polluted, shallow, urban lake? Applied Science-Basel, 10 (11), 3698, https://doi.org/103390-app10113698

Grochowska J, Augustyniak R, Tandyrak R, Łopata M, Parszuto K, Grzegorczyk A, Karpienia M, Płachta A (2019) Report on a hydrochemical study of the water and bottom sediment of the lakes: Mielenko, Karczemne, Klasztorne Małe and Klasztorne Duże in Kartuzy, hydrological and physicochemical studies on surface inflows and outflows, and shore outlets of stormwater carried out in 2019 under Contract No. KIOW/1/2019 of June 28, 2019, titled, "Comprehensive Reclamation of the Lakes: Mielenko, Karczemne, KlasztorneMałe and Klasztorne Duże in Kartuzy", Report made for Kartuzy City Office (in Polish), manuscript

Grochowska, J.K., Tandyrak, R., Augustyniak, R., Łopata, M., Popielarczyk, D., Templin, T., 2021. How we can disrupt ecosystem of urban lakes - pollutants of bottom sediment in two shallow water bodies. Archives of Environment Protection, 47(4), 40-54, https://doi.org/10.24425/aep.2021.139501

Funded by the European Union

Gunn, I. D. M., O'Hare, M. T., Maitland, P. S. , May, L. 2012. 'Long-term trends in Loch Leven invertebrate communities'. *Hydrobiologia*, 681, 59-72. https://doi.org/10.1007/s10750-011-0926-7

Haande S., Moe S. J. & Couture R. M., 2016. Phytoplankton and other monitoring data from Lake Vansjø. Freshwater Metadata Journal 15: 1-8. https://doi.org/10.15504/fmj.2016.15

Haines-Young, R. and Potschin, M., 2013. Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August–December 2012. EEA Framework Contract No EEA/IEA/09/003. Available from: www.cices.eu

Horppila, J., H. Peltonen, T. Malinen, E. Luokkanen, T. Kairesalo, 1998. Top-down or bottom-up effects by fish: Issues of concern in biomanipulation of lakes. Restor Ecol 6(1):20-28 doi:10.1046/j.1526-100x.1998.00613.x

Huttunen, I., Huttunen, M., Piirainen, V., Korppoo, M., Lepistö, A., Räike, A., Tattari, S. , Vehviläinen, B. (2016) A National-Scale Nutrient Loading Model for Finnish Watersheds—VEMALA. Environ Model Assess 21, 83–109. https://doi.org/10.1007/s10666-015-9470-6

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31991L0271 accessed 3.02.2026

Iannaccone, B., Domaracká, L., Tometzová, D. and Gabániová, Ľ., 2024. Assessment of the Recreational Potential of Flooded Quarries in Slovakia. Sustainability, 16(21), 9602. https://doi.org/10.3390/su16219602

Jansen, J., Simpson, G.L., Weyhenmeyer, G.A., Härkönen, L.H., Paterson, A.M., del Giorgio, P.A., Prairie, Y.T. 2024. Climate-driven deoxygenation of northern lakes. *Nat. Clim. Chang.* 14: 832–838. https://doi.org/10.1038/s41558-024-02058-3

Jansen, J., Weyhenmeyer, G.A. Härkönen, L.H., Paterson, A.M., del Giorgio, P.A., Prairie, Y.T. 2025. Divergent oxygen trends in ice-covered lakes driven by ice-cover decline and ecological memory, Proc. Natl. Acad. Sci. U.S.A. 122 (27): e2426140122. https://doi.org/10.1073/pnas.2426140122

Janssen, A.B.G., Hilt, S., Kosten, S., Klein, J.J.M., Paerl, H.W., Van de Waal, D.B., 2020. Shifting states, shifting services: Linking regime shifts to changes in ecosystem services of shallow lakes. Freshw Biol fwb.13582. https://doi.org/10.1111/fwb.13582

Jilbert, T., S. Jokinen, T. Saarinen, U. Mattus-Kumpunen, A. Simojoki, S. Saarni, S. Salminen, J. Niemist & J. Horppila, 2020. Impacts of a deep reactive layer on sedimentary phosphorus dynamics in a boreal lake recovering from eutrophication. Hydrobiologia 847(21):4401-4423 doi:10.1007/s10750-020-04289-9

Jones, R.A., Lee, G.F., 1986, Europhication modeling for water quality management: An update of the Vollenweider OECD model. World Health Organization's Water Quality Bulletin, 11, 67-174, 118 (1986) http://www.gfredlee.com/nutrients/voll_oecd.pdf

Kajak Z., 2001. Hydrobiology-limnology. Freshwater ecosystems (Hydrobiologia-linologia. Ekosystemy wód śródlądowych), PWN Warszawa (book in Polish)

Kotamäki, N., Pätynen, A., Taskinen, A., Huttula, T., & Malve, O. (2015). Statistical Dimensioning of Nutrient Loading Reduction: LLR Assessment Tool for Lake Managers. Environmental Management, 56(2), 480-491. https://doi.org/10.1007/s00267-015-0514-0

Funded by
the European Union

Kowalczewska-Madura, K., Kozak, A., Kuczyńska-Kippen, N., Dondajewska-Pielka, R. and Gołdyn, R., 2022. Sustainable restoration as a tool for the improvement of water quality in a shallow, hypertrophic lake. Water, 14(7), 1005. https://doi.org/10.3390/w14071005

Kowalski H., Grochowska J. K., Łopata M., Augustyniak-Tunowska R., Tandyrak R., 2023, A Unique Application Methodology for the Use of Phosphorus Inactivation Agents and Its Effect on Phosphorus Speciation in Lakes with Contrasting Mixing Regimes, Water, 2023, 15 (1), s. 1-18; https://www.mdpi.com/2073-4441/15/1/67

Lake, P.S. 2012. Resistance, Resilience and Restoration. Ecol Manag Restor, 14: 20-24. https://doi.org/10.1111/emr.12016

Lehtoranta, V., 2013. Vesienhoidon arvo Vesijärvelle Suomen ympäristö. vol 10.

Lewis, A.J., Yun, X., Spooner, D.E., Kurz, M.J., McKenzie, E.R., Sales, Ch.M. Exposure pathways and bioaccumulation of per -and polyfluoroalkyl substances in freshwater aquatic ecosystems: Key consideration. Science of The Total Environment 2022, 822, 153561, https://doi.org/10.1016/jscitotenv.2022.153561

Li, C., Chang, J., Feng, S. and Zhou, S., 2025. From a Coal Mining Area to a Wetland Park: How Is the Social Landscape Performance in Pan'an Lake National Wetland Park?. Land, 14(6), 1305. https://doi.org/10.3390/land14061305

López Bellido, J., E. Peltomaa & A. Ojala, 2011. An urban boreal lake basin as a source of CO2 and CH4. Environ Pollut 159(6):1649-1659 doi:https://doi.org/10.1016/j.envpol.2011.02.042

May, L. and Carvalho, L. 2010. 'Maximum growing depth of macrophytes in Loch Leven, Scotland, United Kingdom, in relation to historical changes in estimated phosphorus loading'. Hydrobiologia, 646, 123-131. https://doi.org/10.1007/s10750-010-0176-0.

May, L., Olszewska, J., Dobel, A., Grant, A. and Spears, B. 2022. The potential role of nitrogen in the restoration of Loch Leven, a shallow loch in the Scottish Lowlands. Report to Scottish Environment, Food and Agriculture Research Institutes (SEFARI), 11 pp.

May, L., Taylor, P., Thackeray, S., Spears, B., Gunn, I., Zaja, E., Gouldsbrough, L., Hannah, M., Glendell, M., Gagkas, Z., Troldborg, M., Roberts, M. and Adams, K., 2024. Mitigating Climate Change Impacts on the Water Quality of Scottish Standing Waters: Report and Appendices. CRW2022_03. Centre of Expertise for Waters (CREW).

Millennium Ecosystem Assessment (MEA), 2005. Ecosystems and Human Well-Being: Synthesis. Washington, DC: Island Press.

Moore, C.C., Corona, J., Griffiths, C., Heberling, M.T., Hewitt, J.A., Keiser, D.A., Kling, C.L., Massey, D.M., Papenfus, M., Phaneuf, D.J., Smith, S.A., Vossler, C.A. and Wheeler, W., 2023. Measuring the social benefits of water quality improvements to support regulatory objectives: Progress and future directions. Proceedings of the National Academy of Sciences, 120(18), e2120247120. https://doi.org/10.1073/pnas.2120247120

Murgante, B., Trabace, G. and Vespe, V., 2023. Combining Tourism Revitalization with Environmental Regeneration Through the Restoration of Piano del Conte Lake in Lagopesole (Southern Italy). In: Gervasi, O., et al. Computational Science and Its Applications – ICCSA 2023 Workshops. ICCSA 2023.

Lecture Notes in Computer Science, vol 14107. Springer, Cham. https://doi.org/10.1007/978-3-031-37114-1_40

Net, L. van der, Staats, N., Coenen, P.W.H.G., Rienstra, J.D., Zijlema, P.J., Arets, E.J.M.M., Baas, K., Baren, S.A. van, Dröge, R., Geertjes, K. , Honig, E., Huet, B. van, Molder R.A.B. te, Montfoort, J.A., Zee, T.C. van der, Zanten, M.C. van. 2024. Greenhouse gas emissions in the Netherlands 1990–2022 National Inventory Report 2024. RIVM report 2024-0017. National Institute for Public Health and the Environment (RIVM). https://doi.org/10.21945/RIVM-2024-0017.

Nile, B.K., Al-Saadi, R.J.M., Abdulameer, L. et al. Climate Change Impacts on River Hydraulics: A Global Synthesis of Hydrological Shifts, Ecological Consequences, and Adaptive Strategies. Water Conserv Sci Eng 10, 48 (2025). https://doi.org/10.1007/s41101-025-00375-y https://doi.org/10.1007/s41101-025-00375-y

Pan Y., Liu B., Cao J., Liu J., Tian S., Du. E, 2021, Enhanced atmospheric phosphorus deposition in Asia and Europe in the past two decades. Atmospheric and Oceanic Letters 14, 100051, https://doi.org/10.1016/j.aosl.2021.100051

Panagopoulos, Y., & Dimitriou, E. (2020). A Large-Scale Nature-Based Solution in Agriculture for Sustainable Water Management: The Lake Karla Case. *Sustainability*, *12*(17), 6761. https://doi.org/10.3390/su12176761

Panagopoulos, Y., Karpouzos, D., Georgiou, P., & Papamichail, D. (2023). Ecosystem Services Evaluation from Sustainable Water Management in Agriculture: An Example from An Intensely Irrigated Area in Central Greece. Environmental Sciences Proceedings, 25(1), 4. https://doi.org/10.3390/ECWS-7-14250

Pelsma, K.A.J., Kox, M.A.R. 2025. Broeikasgasemissies uit zoetwater – Bijlage vergelijking uitstoot. https://www.stowa.nl/deltafacts/klimaat-waterbeheer/emissies/broeikasgasemissies-uit-zoetwater#4003

Pistocchi, A., 2022. Nature-Based Solutions for Agricultural Water Management. European Commission, Joint Research Centre (JRC). Available from: https://publications.jrc.ec.europa.eu

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

Poulsen, M.N., Nordberg, C.M., Fiedler, A., DeWalle, J., Mercer, D. and Schwartz, B.S., 2022. Factors associated with visiting freshwater blue space: The role of restoration and relations with mental health and well-being. Landscape and Urban Planning, 217, 104282. https://doi.org/10.1016/j.landurbplan.2021.104282

Prasanya, J., Kanmani, S. and Senthil Kumar, P., 2024. A review of the wetland's restoration mechanisms and its economic and social benefits. Water Practice & Technology, 19(11), 4355-4377. https://doi.org/10.2166/wpt.2024.241

Qiu, Y., Schertzer, D. and Tchiguirinskaia, I., 2021. Assessing cost-effectiveness of nature-based solutions scenarios: Integrating hydrological impacts and life cycle costs. Journal of Cleaner Production. 329, 129740. Available from: https://doi.org/10.1016/j.jclepro.2021.129740

Rakib, R.J., Sarker, A., Ram, K., Uddin, G., Walker, T.R., Chowdhury, T., Uddin, J., Khandaker, M.U., Rahman, M.W., Idris, A.M. Microplastic toxicity in aquatic organisms and aquatic ecosystems: a Review, Water, Air, and Soil Pollution 2023, 234, 52, https://doi.org/10.1007/s1270-023-06062-9

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

Richardson, J., Miller, C., Maberly, S. C., Taylor, P., Globevnik, L., Hunter, P., Jeppesen, E., Mischke, U., Moe, S. J., Pasztaleniec, A., Søndergaard, M. & Carvalho, L., 2018. Effects of multiple stressors on cyanobacteria abundance vary with lake type. Global Change Biology 24(11):5044-5055 doi:https://doi.org/10.1111/gcb.14396

Rijkswaterstaat. 2018, 14 Jul. Peilbesluit IJsselmeergebied.

Ruangpan, L., Vojinovic, Z., Plavšic, J., Curran, A., Rosic, N. et al., 2024. Economic assessment of nature-based solutions to reduce flood risk and enhance co-benefits. Journal of Environmental Management. 352, 119985. Available from: https://doi.org/10.1016/j.jenvman.2023.119985

Ruuhijärvi, J., P. Ala-Opas & K. Kulo, 2023. Vesijärven kalataloudellinen tarkkailu ja täydentävät kalatutkimukset 2021–2022 Luonnonvara- ja biotalouden tutkimus. vol 64. Natural Resource Institute.

Salmi, P., I. Malin & K. Salonen, 2014. Pumping of epilimnetic water into hypolimnion improves oxygen but not necessarily nutrient conditions in a lake recovering from eutrophication. Inland Waters 4(4):425-434 doi:10.5268/iw-4.4.631

Salonen, K., Sarvala, J., Horppila, J. et al. 2020. Development of Lake Vesijärvi through four decades of remediation efforts. Hydrobiologia 847, 4601–4619. https://doi.org/10.1007/s10750-020-04338-3

Salonen, K., K. Vuorio, M. Ketola, J. Keto & I. Malin, 2023. Development of phytoplankton of Lake Vesijarvi during recovery from eutrophication. Hydrobiologia 850(4):947-966 doi:10.1007/s10750-022-05136-9.

Scopetani, C., D. Chelazzi, A. Cincinelli & M. Esterhuizen-Londt, 2019. Assessment of microplastic pollution: occurrence and characterisation in Vesijarvi lake and Pikku Vesijarvi pond, Finland. Environ Monit Assess 191(11) doi:10.1007/s10661-019-7843-z.

Scott J.T., McCarthy M., 2010, Nitrogen fixation may not balance the nitrogen pool in lakes over timescales relevant to eutrophication management, (Limnology and Oceanography,55(3), 1265-1270)

Shi, R., Peng, X., Cui, Y., Duan, X., Xu, D., Wang, L. and Yeh, A.G.O., 2025. Dynamic exposure to urban lakefront spaces: Unveiling the role of social infrastructure in shaping visitation. Landscape and Urban Planning, 264, 105465. https://doi.org/10.1016/j.landurbplan.2025.105465

Sidiropoulos, P., Tziatzios, G., Vasiliades, L., Mylopoulos, N., & Loukas, A. (2019). Groundwater Nitrate Contamination Integrated Modeling for Climate and Water Resources Scenarios: The Case of Lake Karla Over-Exploited Aquifer. *Water*, *11*(6), 1201. https://doi.org/10.3390/w11061201

Skarbøvik, E., Haande, S., Isidorova, A. and Skjelbred, B., 2025. Vannovervåking i Morsa 2023 og 2024. Bekker, elver og innsjøer november 2022 - oktober 2024. NIBIO report 11 (79). In Norwegian.

Stokke, B.G., Dale, S., Jacobsen, K-O., Lislevand, T., Solvang, R. & Strøm, H. 2021. Artsgruppeomtale, Norsk Rødliste for arter 2021, Artsdatabanken, Rødlista-fugler.

Søndergaard, M., Jensen, J.P., Jeppesen, E., 2003. Role of sediment and internal loading of phosphorus in shallow lakes. Hydrobiologia 506, 135–145. https://doi.org/10.1023/B:HYDR.0000008611.12704.dd

Szulecka, J. (2025) Stakeholder Involvement in Lake Restoration: Stakeholder Mapping and Analysis in Six European Countries, Deliverable 2.1, FutureLakes, available at: https://futurelakes.eu/knowledge-hub/deliverables

TEEB, 2010. The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB. Geneva: UNEP.

Temmink R.J.M., M. van den Akker, C.H.A. van Leeuwen, Y. Thole, H. Olff, V.C. Reijers, S.T.J. Weideveld, B.J.M. Robroek, L.P.M. Lamers en E.S. Bakker, 2021. Herbivore exclusion and active planting stimulate reed marsh development on a newly constructed archipelago. Ecological Engineering 175 (2022) 106474.

Thiemer et al. 2025. Lake restoration innovation pilots in operational scales. FutureLakes Milestone 1.2, Sep 2025

Tzabiras, J., Vasiliades, L., Sidiropoulos, P. et al. Evaluation of Water Resources Management Strategies to Overturn Climate Change Impacts on Lake Karla Watershed. Water Resour Manage 30, 5819–5844 (2016). https://doi.org/10.1007/s11269-016-1536-y

Van Veenendaal, E., Troost, T.A., DeRijk, S., VanEck, L., Kamstra, Y.J.J., Senerpoint Domis, L. submitted.The impact of floating photovoltaics on primary production in a freshwater lake. The Journal of Environmental Management.

Venohr, M., Langhans, S. D., Peters, O., Hölker, F., Arlinghaus, R., Mitchell, L. and Wolter, C., 2018. The underestimated dynamics and impacts of water-based recreational activities on freshwater ecosystems. Environmental Reviews, 26(2), 199–213. https://www.jstor.org/stable/90021711

Vicarelli, M., Sudmeier-Rieux, K., Alsadadi, A., Shrestha, A., Schütze, S., Kang, M.M., Leue, M., Wasielewski, D. and Mysiak, J., 2024. On the cost-effectiveness of nature-based solutions for reducing disaster risk. Science of the Total Environment. 947, 174524. Available from: https://doi.org/10.1016/j.scitotenv.2024.174524

Vinten, A., Sample, J., Ibiyemi, A., Abdul-Salam, Y. and Stutter, M., 2017. A tool for cost-effectiveness analysis of field-scale sediment-bound phosphorus mitigation measures and application to analysis of spatial and temporal targeting in the Lunan Water catchment, Scotland. Science of the Total Environment. 586, pp.631–641. Available from: https://doi.org/10.1016/j.scitotenv.2017.02.029

Vollenweider, R.A., 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as factors in eutrophication. OECD Directorate for Sci. Affairs, Paris, 27.

Vollenweider, R.A., 1976, Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol., 33.Blignaut, J., Aronson, J., & de Groot, R. (2014). Restoration of natural capital: A key strategy on the path to sustainability. *Ecological engineering*, *65*, 54-61.

Zienkiewicz, A., 2016. The role of natural environment in the development of tourism in the Kashubian Lake District (on the example of Kartuzy County). Geosport for Society, 4(1), pp.37–50. Available from: https://geosport.uoradea.ro/2016_1/2016_12_GSS_Zienkiewich_16.04.04.015.pdf

Funded by
the European Union

Annexes

I) Detailed costs and benefits

Table A. 1. Detailed implementation costs of restoration measures. Source: DS-Annexes a - f.

Demonstration Site	Measure	Implementation costs (K€; est. 2025)	Landscape	Measure type	Year
Lake Vesijärvi	Biomass removal - fish	67,4	In-lake	NbS / CBS	2007-2014
Lake Vesijärvi	Aeration	560	In-lake	Technical	2007-2014
Lake Vesijärvi	Sedimentation ponds/wetlands	520	Agricultural	NbS	2015-2017
Lake Vesijärvi	Sewage treatment	8 500	Urban	Grey	1976
Lake Vesijärvi	All	2300	All	All	1989-1994
Lake Vesijärvi	All	1580	All	All	2002-2007
Kartuzy Lakes	P inactivation agent doses	328	In-lake	Other	2020-2023
Kartuzy Lakes	Sediment removal from lake	10942	In-lake	CBS	
Kartuzy Lakes	Biomass removal - fish	74	In-lake	NbS / CBS	
Kartuzy Lakes	Recreational infrastructure	2326	Urban	Blue Economy	
IJssel complex	Island creation	19200	In-lake	BfS	2004
IJssel complex	Refuge area	48400	In-lake	BfS	2005
IJssel complex	Island creation	96300	In-lake	BfS	2021
IJssel complex	Natural foreshore creation	786900	Lake Shoreline	NbS	2026
IJssel complex	Natural foreshore creation	7800	Lake Shoreline	NbS	2018

Funded by the European Union

IJssel complex	Natural foreshore creation	8700	Lake Shoreline	NbS	2020
IJssel complex	River connectivity	67000	River	BfS	2026
Lake Karla		202851,462	In-lake	Other	
Lake Karla		41040	In-lake	NbS	
Lake Karla		13838,761	Agricultural	Grey	
Lake Karla		21060	Agricultural	Land management	
Lake Karla		19710	Urban	Grey	
Lake Karla		14310	Lake shoreline	Blue Economy	
Lake Karla		68644,068	Agricultural	Other	
Lake Karla		51208,635	Other	Other	
Loch Leven	Sewage treatment	225	Urban	Grey	1993
Loch Leven	Sewage treatment	67	Urban	Grey	1997
Loch Leven	Sewage treatment	7700	Urban	Grey	
Loch Leven	Sewage treatment	3100	Urban	Grey	
Lake Vansjø	Riparian/Floodplain restoration	2	Agricultural	NbS	
Lake Vansjø	Grass covered waterways	3,7	Agricultural	NbS	
Lake Vansjø	Catch crops	0,1	Agricultural	Land management	
Lake Vansjø	Sewage treatment	21692	Urban	Grey	2002-05 and 2006-08
Lake Vansjø	Sewage treatment	14133	Urban	Grey	1999-2012
Lake Vansjø	Establishing and restoring riparian zones	220	River	NbS	

Lake Vansjø	total costs for mainly agricultural measures	14 222,30	Agricultural		2013-2024

Table A.2. Direct and indirect economic benefits

Demonstration Site	Type of benefit	Benefits	Benefits annual value (K€; est. 2025)	Source
Lake Vesijärvi	Regulating	water quality improvement	770	DS-Annex a, Lehtoranta (2013)
Lake Vesijärvi	Indirect benefits	CAP subsidy /farmer to maintaining the wetland	4626	DS-Annex a
Lake Vesijärvi	Regulating	decreased P loading by the wetlands (water purification)	300	DS-Annex a
Lake Vesijärvi	Provisioning	groundwater abstraction	1 825 000	DS-Annex a, Market price of water sourced from https://www.joo-kodit.fi/en/water-unit-prices?utm
Lake Vesijärvi	Provisioning	Fisheries	15.3	DS-Annex a (Annual catch of cyprinids=18000 kg) and using the industrial value of 0.8€/kg for cyprinid, sourced from https://www.luke.fi/en/statistics/producer-prices-for-fish/producer-prices-for-fish-2024?utm
Lake Vesijärvi	Cultural	Recreational fishing	5 470	DS-Annex a
Kartuzy Lakes	Cultural	boating on SUP paddle boards during summer	4	Zienkiewicz (2016), Cichoń (2019)
Kartuzy Lakes	Provisioning	recycling the removed sediment for P reuse after the	148 800	Volume sourced from the Demo DS-Annex, Market price of P fertilizers sourced from https://www.gospodarka.sos.pl/najnowsze-ceny-

		remove of polluted sediment		nawozow-fosforowych-sierpien-2025-32861152.html?utm
Kartuzy Lakes	Indirect benefits	Job creation	166	Based on median wage in the country
IJssel complex	Provisioning	in-lake wind energy production	57,1	Demo Annex, price of energy sourced from https://zichtopenergie.nl/prijsontwikkelingen/ontwikkelingen-electriciteitsprijzen/
IJssel complex	Regulating	carbon sequestration generated by the constructed wetland	32,6	Demo Annex, Baren et al.(2025), average carbon price in the voluntary carbon market sourced from https://carbon-pulse.com/412434/
IJssel complex	Provisioning	fisheries	4 290	https://vakbladvoedingsindustrie.nl/en/article/urker-fish-auction-solid-turnover-thanks-to-pike-perch?utm_
Lake Karla	Provisioning	Irrigation water	2 986	DS-Annex d
Lake Karla	Provisioning	DRINKING WATER SUPPLY	2 550	DS-Annex d
Lake Karla	Provisioning	Fisheries	36,7	DS-Annex d
Lake Karla	Cultural	RECREATION	117,4	DS-Annex d
Lake Karla	Indirect benefits	Job creation	373,3	DS-Annex d
Loch Leven	Provisioning	Fisheries	592	DS-Annex d
Loch Leven	Cultural	Water view; Trail quality; Riverbank accessibility	3 900	McDougall and Craig (2020)
Loch Leven	Regulating	algal blooms reduction	2 300	May et al. (2024)
Loch Leven	indirect benefits	Extra profits realised by businesses around the loch	1350	DS-Annex e

Loch Leven	Regulating	Reduction of phosphorus (P entering)	466,2	Vinten et al. (2017)
Lake Vansjø	Provisioning	drinking water source	65 250	based on estimations from https://www.sandnes.kommune.no/sti/vann-og-avlop/kommunale-avgifter/priser-vann-og-avlop/
Lake Vansjø	Provisioning	water for agricultural irrigation	11100	Volumes are estimations over a typical 4-month summer irrigation season in the country Unit price is proxied by the standard water consumption fees payed by farmers (connected to a municipal water system) charged by the municipality: https://www.moss.kommune.no/alle-tjenester/vann-og-avlop/priser-og-gebyrer-vann-og-avlopstjenester/
Lake Vansjø	cultural	recreational activities (boating, bathing, ice skating, fishing),	67 200	canoe/kayak (person/half day) = 400NOK = 34-35 € 1 NOK ≈ 0.085–0.088 EUR https://wildoslo.com/kayak/kayak-rental-vansjo-moss/

II) Indicators pertaining to the restoration criteria

Table II.1. Indicators pertaining to the restoration criteria.

Criterion Type	Criterion	Indicator Code	Short Indicator Name	Specific Indicator	Unit
Environmental	Biodiversity Net Gain	BD1a	Habitat condition	<Habitats Directive habitat code>	% area in favourable/good condition (HD)
		BD1b	Habitat trend	<Habitats Directive habitat code>	HD condition trend (stable, improving, deteriorating)
		BD2a	Species condition	<Habitats Directive - species Latin name>	Species condition (abundance?)
		BD2b	Species trend	<Habitats Directive - species Latin name>	Species trend
		BD3a	Bird condition	<Birds Directive - species Latin name>	Bird species condition (bird numbers) (BD)
		BD3b	Bird trend	<Birds Directive - species Latin name>	BD trend
		BD4	Total lake area under protected status	Area of habitat <HD habitat code>	(ha)
		BD5	Length of shoreline restored	Length of habitat <HD habitat code - shoreline>	km of shoreline length
		BD6	Area of island habitat created	Area	(ha)
		BD7	Presence of invasive non-native species	<names of invasive species>	(presence/absence, abundance, trends, controls)
		BD10	Other	(e.g. locally important species)	<provide units>
	WFD	WFD1	Ecological status of waterbody	Status class of <name of waterbody>	WFD status class (and EQR)
		WFD2	EQR / Ecological status of BQE	Phytoplankton	WFD status class (and EQR)
		WFD3	EQR / Ecological status of BQE	Macrophytes	WFD status class (and EQR)
		WFD4	EQR / Ecological status of BQE	Benthic Invertebrates	WFD status class (and EQR)
		WFD5	EQR / Ecological status of BQE	Fish	WFD status class (and EQR)
		WFD6	Other	<specify indicator> e.g. Zooplankton	<provide units>
	Zero Pollution	ZP1	Chemical status of waterbody	WFD status class	WFD class

		ZP2	EQS of specific priority chemicals e.g. PFAS	<parameter name> e.g. PFAS	EQS / status class
		ZP3	Supporting: Nutrient concentrations	total nitrogen	(mg/L)
		ZP4	Supporting: Nutrient concentrations	orthophosphate-phosphorus (PO4-P)	(mg/L)
		ZP5	Supporting: Nutrient concentrations	nitrate-nitrogen (NO3-N)	(mg/L)
		ZP6	Supporting: Nutrient concentrations	ammonium-nitrogen (NH4-N)	(mg/L)
		ZP7	Dissolved organic carbon (DOC)	Dissolved organic carbon (DOC)	(mg/L)
		ZP8	Biological oxygen demand (BOD)	BOD	(mg/L)
		ZP9	Pathogenic bacteria (e.g. E. coli)	<parameter name>	(MPN/100 mL)
		ZP10	Microplastics (<5 mm)	<parameter name>	(enter unit)
		ZP11	Macroplastics (>5 mm)	<parameter name>	(enter unit)
		ZP12	Other (e.g. measures to reduce storm overflows)	<parameter name>	(enter unit)
Climate	**Flood resilience**	FR1	Increased storage capacity of lake		(m3)
		FR2	Increased storage capacity of catchment wetlands		(m3)
		FR3	Area of newly designated areas for flooding (ha)		(ha)
		FR4	Area of rewetted wetlands in catchment (ha)		(ha)
		FR5	Other (could be a narrative about measures to reduce risks from storm events)	<specify>	<units>
	Drought resilience	DR1	Increased volume of lake		(m3)
		DR2	Increased volume of catchment wetlands		(m3)
		DR3	Area of agricultural lands with applied schemes for water retention (ha)		(ha)
		DR4	Change of groundwater abstraction by sector over time (e.g. last 20 years) (m3)		(m3)
		DR5	Change of surface water abstraction over time (e.g. last 20 years)		(m3)

		DR6	Number of households implementing water-saving technologies (no. of households)		(no. of households)
		DR7	Other	<specify>	<units>
	Climate regulation service	CR1	Greenhouse gas emissions (measured or modelled)		equiv. g C / year
		CR2	Carbon sedimented / sedimentation rate		g C / year
		CR3	Other	<specify>	<units>
Societal	Health & Well-being	HWB1	Bathing water quality: cyanobacteria	Visible surface scums	Presence/absence
		HWB2	Bathing water quality: cyanobacteria	Biovolume	mm3/ml
		HWB3	Bathing water quality: E. coli		cfu/100 ml
		HWB4	Bathing water quality: Intestinal enterococci		cfu/100 ml
		HWB5	Other health-related indicators (e.g. narrative about measures to improve well-being)	<specify indicator>	<units>
	Inclusivity	In1	Number of visitors to website(s) describing lake protection and restoration measures		count
		In2	Total number of participants in information sessions about lake protection/restoration		count
		In3	Inclusivity in lake basin management board (See T2.1 & 2.4 classifications)	Specify row for each group	count
		In4	Formal public consultation on restoration/management plans		count
		In5	Numbers involved in citizen science activities		count
		In6	Numbers involved in lake management/restoration activities		count
		In7	Other inclusion indicators	<specify indicator>	<units>
	Recreation	Rec1	Numbers involved in angling		count
		Rec2	Numbers involved in swimming		count
		Rec3	Numbers involved in water sports		count
		Rec4	Numbers involved in birdwatching		count
		Rec5	Numbers involved in general recreation around lake		count

		Rec6	Length of active travel routes around or connected to the lake (walking/cycling)	<specify>	km
		Rec7	Features supporting nature-friendly recreation (e.g. bird hides, visitor centres)	<specify indicator>	narrative
		Rec8	Other	<specify indicator>	<units>
Economic	Circular Economy	CE1	Water capture for reuse/re-allocation to the environment		(m^3)
		CE2	Sediment reuse (weight)		kg
		CE3	Sediment reuse (value)		€
		CE4	Biomass harvested (weight)	<specify>	kg
		CE5	Biomass harvested (value)	<specify>	€
		CE6	Other	<specify>	<specify>
	Blue economy	BE1	Jobs created attributable to restoration activities	Jobs created attributable to restoration activities (jobs created by restoration activities directly implemented by the beneficiary and/or outsourced to contractors)	(number)
		BE2	Jobs created attributable to restoration outcomes	Jobs created attributable to restoration outcomes (e.g. jobs created following improved condition of lake)	(number)
		BE3	Net Value of establishments providing recreation and tourism services	Turn-over and Gross and Net Value Added of establishments associated in and around lake (hotels, camping sites, equipment (e.g. canoe) rental agencies, restaurants, bars)	€/year
		BE9	Value of fishery	Based on number of fishing licenses sold or value of harvested fish	€/year
		BE10	Other	<specify>	<units>
Sectors	Sustainable Agriculture	Agri1	Inputs: Water consumption by agriculture	Water consumption (m3)	m3/year
		Agri2	Inputs: Fertiliser application	Fertiliser application	tonnes/year
		Agri3	Inputs: Pesticide application	Pesticide application	kg/year
		Agri4	Outputs: farm productivity	Farm production	kg/year

		Agri5	Outputs: farm productivity	Total farm income	€/year
		Agri6	Utilisation: Land cover (Corine class)	2.1 Agricultural areas (arable)	ha
		Agri7	Utilisation: Land cover (Corine class)	2.2 Agricultural areas (permanent crops)	ha
		Agri8	Utilisation: Land cover (Corine class)	2.3 Agricultural areas (pasture)	ha
		Agri9	Utilisation: Land cover (Corine class)	2.4 Agricultural areas (heterogeneous)	ha
		Agri10	Utilisation: Land cover (Corine class)	3.1 Forests	ha
		Agri11	Utilisation: Land cover (Corine class)	4.1 Inland wetlands (marshes and peat bogs)	ha
		Agri12	Utilisation: Land cover (Corine class)	5.1 Inland waters (water courses and water bodies)	ha
	Sustainable transport	Tra1	Measures to mitigate impact of navigation: NbS, technical, regulations (speed limits)	Navigation measures	(type and size of the measures)
		Tra2	Intensity and type of navigation (cargo vessels, passenger ships, sport boats	Navigation intensity	(type of boats per day (P))
		Tra3	Others	<specify> e.g. plant biomass or sediment removed for navigation	(narrative)
	Sustainable energy	Energy1	Renewable energy production (e.g. hydropower, solar, heat from lakes or catchment measures)	Due to lake or catchment measure	kWh
		Energy2	Energy consumption changes as a result of lake or catchment measures (kWh)	Due to lake or catchment measures (e.g. artificial aeration, harvesting biomass)	kWh
		Energy3	Other	<specify> (e.g. Removed plant biomass, removed sediment mass for navigation)	<units>
	Sustainable tourism	Tour1	Total visitor numbers (tourists and locals)	Total visitor numbers	Count/year
		Tour2	Number of overnight stays in an area on an annual basis		(number/year)
		Tour3	Number of businesses providing tourism and recreation services		(number)
		Tour4	Catch-per unit effort of fishery	Measure of sustainability of fishery	number caught/hour/angler

		Tour5	Infrastructure modification of lake shore for tourism (bank protection, barriers, impoundments, dredging)	Negative infrastructure alterations <specify> (e.g. % of natural banks, m^3 of dredging)	<specify>
		Tour6	Infrastructure supporting nature-friendly tourism (e.g. paths, visitor centres)	Positive infrastructure alterations	number or narrative
		Tour7	Other	<specify>	number or narrative
	Water supply and sanitation	WSS1	Total water consumption in catchment (supplied)		m3/year
		WSS2	Population not connected to sewerage		count
		WSS3	No. of storm overflows to lake		Number per year
		WSS4	Other		<specify>

III) Ecological indices

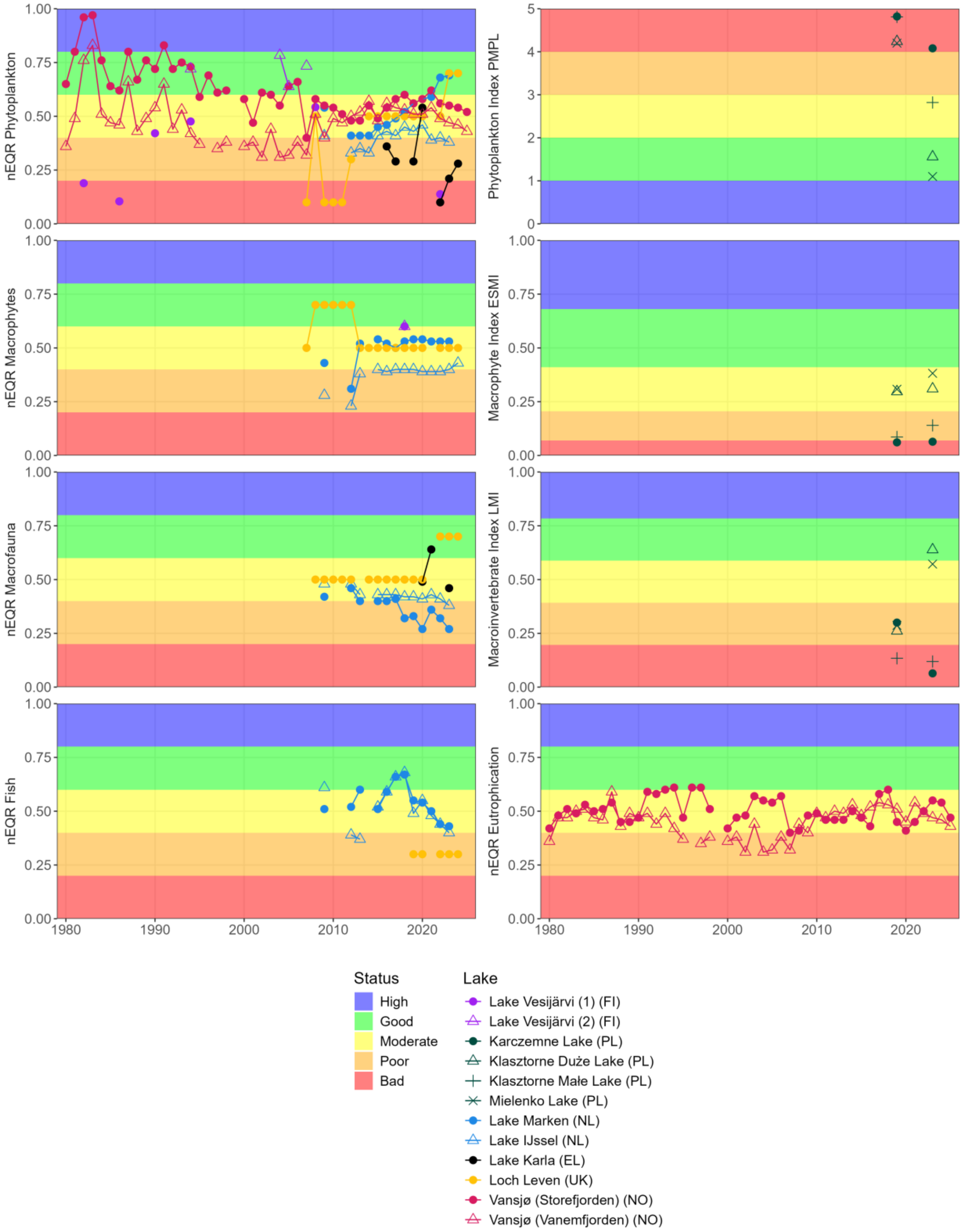


Figure C.1. Ecological indices (not converted) at all Demonstration Sites. Data from Loch Leven has been transformed from the status classes to numeric values with the values: Bad = 0.1, Poor = 0.3, Moderate = 0.5, Good = 0.7.