MERLIN

D1.8 – Manuscript on reviewing citizen science in stream monitoring and restoration

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Imprint

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Cover picture: Participants of the FLOW Project team (Saaletreff) sorting macroinvertebrates for identification to the family level at Ammerbach, Jena, Germany (© Runkewitz, 2024).

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Key messages

1. Citizen science offers a powerful approach for monitoring rivers and assessing the effectiveness of stream restoration measures. A systematic global review synthesises information from 87 citizen science stream monitoring projects.
2. The majority of projects were located in Europe, the United States and Canada, highlighting an uneven global distribution.
3. Citizen scientists most commonly monitor biological parameters, e.g. macroinvertebrates, and hydro-morphological parameters such as e.g. stream flow.
4. The majority of projects provide training opportunities (72%), and apply data quality control measures (84%), demonstrating efforts to ensure data reliability.
5. Collaborative, locally adaptive and co-created project designs that integrate local knowledge, communities, and organisations strengthen trust, data acceptance and long-term engagement.
6. Future initiatives should build on the foundations of existing citizen science projects, including established methods, tools and data-sharing infrastructures.

Executive Summary

Freshwater ecosystems are increasingly threatened by anthropogenic pressures such as pollution, habitat modification, and biodiversity loss. To address these challenges, policy frameworks like the European Water Framework Directive (WFD) aim to achieve a good ecological status of all water bodies through systematic monitoring and restoration measures. In this context, citizen science—the involvement of non-professional volunteers in scientific research—has gained attention as a potential tool to enhance monitoring efforts and raise public awareness.

This study presents a systematic review of citizen science initiatives focused on the monitoring of rivers and streams. The review aims to (1) assess the current global status of citizen science-based freshwater monitoring, (2) identify commonly used methods and ecological indicators, and (3) evaluate the potential contribution of citizen science to the assessment of restoration outcomes. By synthesizing existing research, the study provides insights into current practices, methodological trends, and future perspectives for integrating citizen science into freshwater ecosystem management. The present study focuses on publications identified on Web of Science (www.webofscience.com). In total, **87 projects** were included in the analysis. Citizen science projects contribute to raising awareness of nature and enable the interests of the local community to be represented and considered. Biological indicators such as macroinvertebrates and fish were frequently studied. These were also examined in connection with hydro-morphological and chemical water quality indicators. The study identified **eight monitoring** projects that evaluate the **impact of restoration measures**, with two involving restoration activities carried out by citizens themselves. However, several reviews point out that the impact of restoration measures remain insufficiently studied, as monitoring is often lacking and ecological responses may take 10-20 years to become apparent. The present analysis shows that existing citizen science monitoring projects are suitable for the before and after monitoring of restoration efforts. Their established structures and methodologies provide a valuable foundation for co-creating and implementing restoration measures, while their adaptability to local ecological and social contexts supports the principles of adaptive freshwater ecosystem management.

Content

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1 Introduction

Since the beginning of human civilization, freshwater ecosystems have been exploited as food resources and degraded as transportation ways (Marsh, 2009), and receive nutrient, pollutant and sediment input external sources. As one consequence, until the end of the 20th century river corridors throughout Eurasia and North America were extensively modified in various aspects, leading to only 40% of all surface water bodies being in a good ecological status to date (Kristensen 2018, Wohl, 2014). Water pollution (including nutrients, pesticides, macro- and microplastics and other toxicants), channelisation and modified flow regimes, modified or disconnected riparian zones and invasive alien species are the main drivers for a constant loss of biodiversity and ecosystem functions in river ecosystems (Canfield et al., 2010; Ellis et al., 2010; Meijer et al., 2021). The global decline in stream biodiversity and ecological status needs urgent social responses (United Nations, 2025; White & Walsh, 2020).

In Europe, these drivers have been addressed through the **Water Framework Directive** (WFD), that was introduced in 2000 and aims to achieve a **good ecological status** for all EU rivers, lakes, groundwater, coastal or transitional waters. Good ecological status is achieved when the hydro-morphological, biological and water quality indicators of rivers and streams are in **near-natural status** specific to the relevant ecoregion and river type (European Commission, 2000; Grizzetti et al., 2019). Therefore, the WFD provides a **framework** for the protection and restoration of aquatic ecosystems with sustainability targets for aquatic ecosystems to maintain their ecological function and ecosystem services. In 2011, the European Union adopted the EU Biodiversity Strategy with six targets, which aim to enhance ecosystems and their services by **restoring and conserving nature**. The good ecological status is assessed by using biological elements such as phytoplankton, benthic invertebrates, aquatic flora and fish as well as chemical and hydro-morphological elements. (European Commission, 2000; European Commission, 2019a; Grizzetti et al., 2019). In addition, in 2015, the United Nations signed the Agenda for Sustainable Development, a strategic framework comprising 17 **Sustainable Development Goals** (SDGs) that are supposed to be reached by 2030. National governments have the responsibility to measure SDGs targets and indicators. One of the SDGs is the access to clean water and sanitation (Goal 6) with the indicator 6.3.2 promoting the increase of water bodies with **good ambient water quality**. The principles of the agenda are to be visible, universal and **participatory**, which require a collaboration between scientific researchers, decision-makers, institutions and individuals. But a lack of regular monitoring leaves a gap in knowledge and water quality of freshwater ecosystems may fall below required standards.

To reach ecological targets, river restoration is a key component to **improve habitats, water quality or river recreation**. River or stream restoration describes a variety of modifications (e.g., bank stabilization, channel reconfiguration, instream habitat improvement and instream species management) to enhance the hydrologic, geomorphic and or ecological processes of a river or a stream. Restoration is nowadays one of the most prominent areas of applied water management, reflected in the global increase in river restoration projects in the last decades (Feld et al., 2011; Sanna et al., 2024; Wohl et al., 2005, 2015, Pander & Geist, 2013). In 2024, member states in the EU have committed through the Nature Restoration Regulation (NRR) to restore 25.000 kilometres of river length by 2030. Despite increasing restoration efforts and ambitious targets, knowledge about restoration outcomes and their impact on abiotic and biotic river properties remains limited (Bernhardt & Palmer, 2011; Feld et al., 2011; Morandi et al., 2014). Rubin et al. (2017) state in their review that most restoration projects remain unevaluated due to a lack of systematic monitoring. Similarly, Palmer et al. (2010) found that only two of the 78 projects they identified achieved biological success but also noted that most studies lacked sufficient monitoring data to determine which factors may have influenced restoration outcomes.

To be effective, river restoration projects need a **Before-After-Control-Impact** (BACI design) (Edwards et al., 2018). River restoration efforts are often assumed to benefit the ecosystem and increase the biodiversity and abundance of species, but this hypothesis is rarely tested or validated. That is why quantitative **monitoring** methods are needed to assess the effects of restoration measures. The results of the monitoring could also help to save resources by informing an **adaptive restoration** process.

Limited financial and human resources often result in insufficient monitoring. One effective way to address this gap is through citizen science (Tulloch et al., 2013). **Citizen science**, the involvement of volunteers in scientific research and monitoring has become an important tool to engage the public in joint learning-by-doing, enabling knowledge creation and civil participation (Hecker et al. 2018, Turrini et al. 2018; von Gönner et al. 2023, 2024). It can help raise public awareness of (local) environmental issues, increase democratisation of decision-making processes, and promote stewardship for single species up to whole ecosystems (Edwards et al., 2018, Bonney et al., 2009). It involves the participation of volunteers in scientific research and monitoring, allowing data collection at scales otherwise difficult to achieve Volunteer water quality monitoring has become a major component of citizen science, with NGOs, anglers and local associations frequently involved (Alam, 2013; Bonn et al., 2021; Bowler et al., 2021). Collaborations with schools further promote awareness and stewardship of river and stream ecosystems from an early age (Edwards et al., 2018; Firehock & West, 1995). Ultimately, citizen science can create impact by not only fostering environmental awareness but enabling a sense of collective efficacy and also collective action (von Gönner et al. 2023, 2024).

Alongside ecological status monitoring efforts there is an increasing need for **restoration efforts** in degraded freshwater ecosystems. But restoration projects often lack monitoring and assessment of their impact. Citizen science monitoring has the potential to measure the outcomes of these restoration efforts and a solution for implementing a before-and-after restoration monitoring (Edwards et al., 2018).

Furthermore, restoration and its planning often show a big potential for conflict of interest between different stakeholder groups. Citizen science could be a solution to **engage stakeholders** in the restoration process, especially as part of the monitoring of its ecological outcomes. Restoration is not only an ecological, but also a complex social process, influenced by many factors. Engaging stakeholders and citizens can show a positive effect on the awareness with their local stream and river and a better understanding for nature (Alam, 2013; Smith et al., 2016).

To assess the function and effectiveness of citizen science in stream monitoring of rivers and streams worldwide, this study employs a systematic review approach. A systematic review uses explicit and systematic methods, to be able to summarise existing studies on one or multiple research questions (Higgins et al., 2019).

The following research questions were addressed:

→ Which types of citizen science projects exist worldwide for the ecological monitoring of rivers and streams?

We assess the status of citizen science monitoring projects worldwide. Specifically, we examine how many projects exist and how they are spatially distributed. Furthermore, each project is categorized according to its temporal scope, participant scale, and target groups, and evaluated with regards to the provision of citizen science training. The analysis highlights well-designed citizen science projects and their key characteristics.

→ Which methods and indicators are used to assess river hydro-morphology, chemical water quality and biological communities?

The status of freshwater ecosystems is commonly assessed using hydro-morphological, biological, and chemical water quality indicators (European Commission, 2000). Citizen science monitoring projects apply a range of methods and indicators to evaluate the condition of rivers and streams. Here, we identify and categorize the indicators and methods used in citizen science projects to assess the ecological status of freshwater systems. The indicators are grouped into three main categories: hydro-morphological indicators, such as riverbank structure, substrate composition, and other morphological features; water quality indicators, which are closely related to pollution levels and chemical composition; and biological indicators, including macroinvertebrates, fish, or other aquatic organisms that reflect ecosystem health.

→ To what extent can the citizen science monitoring data be used to assess the ecological effects of restoration measures?

Finally, we evaluate whether and how citizen science monitoring projects have the potential to support restoration projects by assessing the before-and-after restoration impact. Based on our findings we provide recommendations on opportunities and challenges when and how to employ citizen science in stream monitoring and restoration assessments.

2 Methodology

2.1 Pilot abstract screening and generating final search string

This systematic review follows the 27-item checklist of the PRISMA 2020 statement paper to ensure a transparent, complete and accurate reporting (Page et al., 2021). The focus of this systematic research was on published papers, with grey literature excluded from consideration. The study was conducted following a five-step methodological process: (1) pilot abstract screening (2) development of the final search string (3) final abstract screening, (4) full text screening and (5) analysis. In an initial pilot phase, a preliminary pilot abstract screening was conducted to gain an overview of the existing body of literature on the topic and to create exclusion and inclusion criteria. Several search strings were tested in Web of Science and Scopus (see Appendix, Fig. A1).

After removing duplicate papers identified through different search strings, the screening was conducted by two researchers to ensure objectivity. Based on the initial overview of existing studies, a decision tree was developed in accordance with the established inclusion and exclusion criteria (Figure 1), following the example provided by Foo et al. (2021). This tree was applied during both the final abstract screening and the full-text screening. The "ecological parameters" (Step 4) considered in this review were defined to provide examples and clarify the eligible parameters.

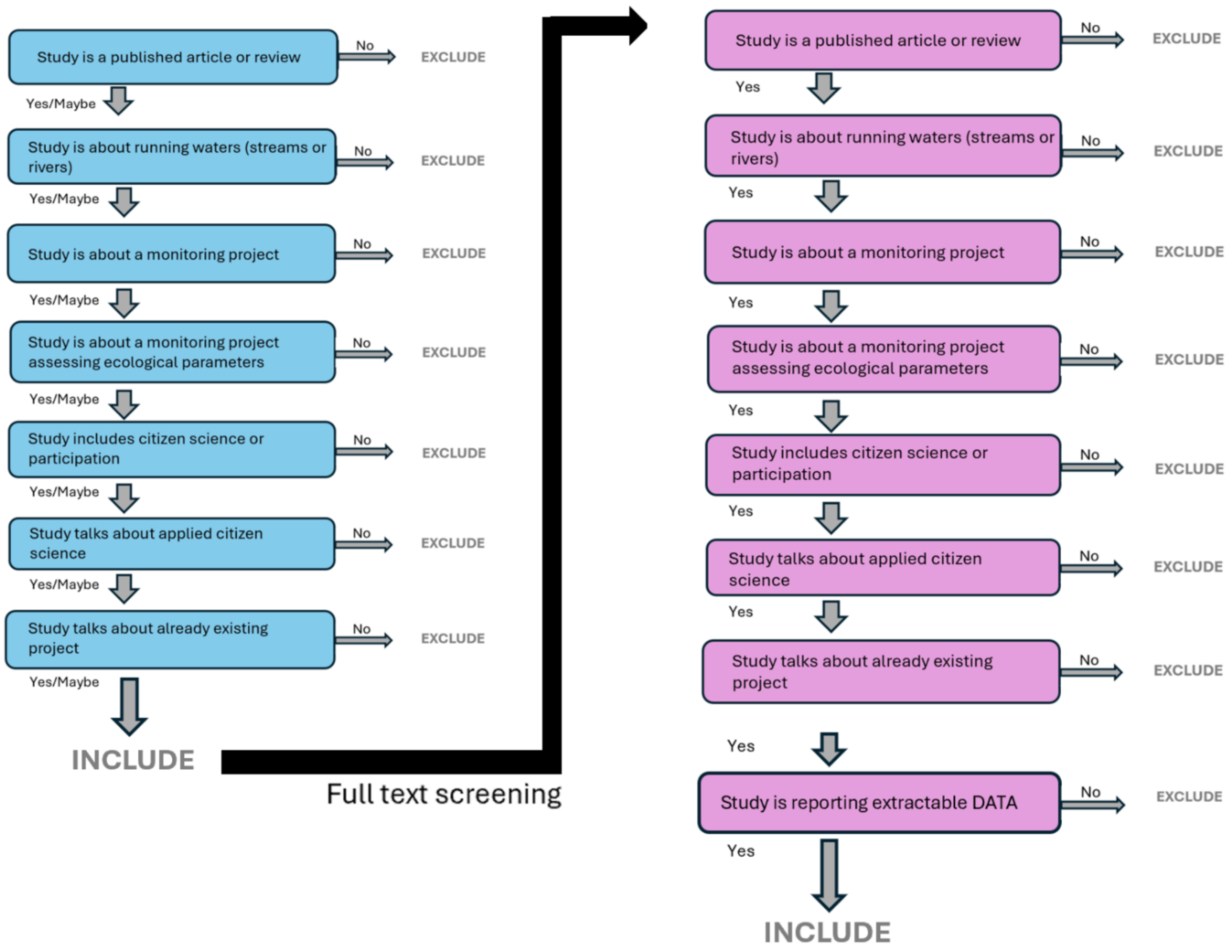


Figure 1 - Decision tree for the abstract and final screening. Generated out of our exclusion and inclusion criteria.

Table 1 - Ecological and monitoring-related keywords and search terms used for the screening process

Hydro-morphology	Water quality	Biological communities
Meandering of watercourse	Temperature	Birds
Erosion	Oxygen	Mammals
Barriers/dams	pH	Amphibians
Flow diversity	Conductivity	Fish
Substrate diversity	Nitrate	Invertebrates
River profile	Nitrite	Plants
Water level	Phosphate	Algae
Bank stabilization	Pesticides	
Riparian vegetation	Metals	
Buffer strip	Other toxicants	
Land use	Macroplastics	
	Microplastics	

The initial step in the process involved identifying common terms and categorising them into thematic groups based on their synonymous meanings. The resulting groups were "participation", "monitoring" and "ecosystem" (see Appendix Fig. A1a). Following the grouping of synonyms, terms frequently occurring in unrelated papers were defined as exclusion terms. The pilot screening thus offered an overview of topics commonly associated with the preliminary search strings, enabling the exclusion of those not relevant to the study (see Appendix Fig. A1b). Based on this iterative refinement process, the final search string was generated and subsequently adapted for use in the Web of Science database.

Using the generated search string, a total of 845 papers were retrieved from Web of Science (see Appendix Fig. A1c) and subsequently analyzed in the final abstract screening.

2.2 Final abstract screening and full text screening

Using the decision tree (Fig. 1), the final abstract screening was carried out independently by three researchers to ensure objectivity and resulted in a total of 170 papers. Each step of the screening process was carefully documented, including the specific reasons for excluding papers from the final selection (see Appendix Tab. A3). The same exclusion criteria were applied during the full text screening (Fig. 1b). After removing one duplicate publication, a total of 85 papers remained for analysis (see Appendix Tab. A9).

2.3 Analysis

Of the 85 papers chosen for analysis 83 described a single citizen science project while two papers described two projects, resulting in a total of 87 identified projects. We defined a *project* in the context of citizen science as a goal-oriented and organized activity in which participants — citizens and scientists — generate, use, or apply knowledge. A *project* may be standalone, addressing a specific local or thematic question, or it may be embedded within broader research frameworks or platforms, where shared infrastructure and data contribute to multiple scientific or societal objectives. The scope of a *project* can range from small, community-driven initiatives to larger, multi-institutional efforts in which scientists employ citizen science platforms as part of their own research agendas. During the analysis, relevant information was extracted from the textual data and organized into predefined parameter categories, which are described in Table 2 (see also Appendix Table A4). Information from each project was grouped into four main categories: general project data, participation characteristics, monitoring focus, and relevance to restoration. These categories were selected to align with the study's research questions and to allow for a systematic comparison of the ecological and participatory dimensions of citizen science monitoring projects. Additional categories, such as data quality control and training, were also analysed, given the ongoing discussion about the reliability of citizen science data (e.g. Bonn et al, 2021).

Table 2 – Summary of the information extracted from the 85 reviewed papers, including detailed description of the analysed parameters

Recorded information	Description of recorded information
Project name	Name of the citizen science project described in the paper.
Project duration (years)	Duration from start to end date; if end date not mentioned, current date used. Frequently not reported, hence excluded from statistical analysis.
Project start-end	Start and end years as reported; if end year not specified, current year assumed.
Country	Country or countries where the project is implemented.
Location	Precise location of the river or stream if mentioned.
Project lead	Type of lead: government, NGO, community, agency or research institute.
Spatial scale	Geographical scope: regional (single area), national (entire country), international (multiple countries) or global (multiple continents).
Type of waterbody	Stream, river, or combination with a lake.
Standardised protocol	Whether the project mentions use of a standardised monitoring protocol.
Indicator: hydro-morphology	Whether the project includes the monitoring of hydro-morphological parameters defined in Table 1.

Indicator: water quality	Whether the project includes the monitoring of water quality parameters defined in Table 1.
Indicator: biology	Whether the project includes the monitoring of biological parameters defined in Table 1.
Methods	Main methods grouped as: bioindicators (sampling and taxa identification), chemical indicators (standardised sampling kits), hydro-morphological or other indicators (surveys), photo submission to experts, sample collection and laboratory analysis immobile sensors/gauges.
Participant prior knowledge	Whether participants had prior relevant knowledge; often not reported and excluded from statistical analysis.
Participant target group	Schools, universities, angling clubs, NGOs, Indigenous communities, other initiatives or community members (locals, residents, farmers).
CS training	Inclusion of citizen science training; delivery format: onsite or online.
Peer learning/mentoring	Hierarchy among participants: group leaders or experienced participants mentoring others.
Number of participants	The number of participants reported; often missing, hence excluded from statistical analysis.
Monitoring frequency	How often the river or stream is monitored (e.g., weekly, monthly, yearly or irregular)
Data quality control	Presence of expert validation or other quality control measures, such as for example control samples or photo validation (e.g. Williams et al, 2016; Dwivedi et al, 2021).
Type of participation	Contributory, collaborative or co-created (Shirk et al., 2012) based on participant involvement in project design, data collection, and analysis.
Participant outcome	Reported benefits or disadvantages for participants.
Link to monitoring framework	Mention of SDGs, WFD, or other frameworks.
Restoration activity	Monitoring or implementation of ecological restoration measures.

The first 21 papers were analysed independently by three scientists. This analysis served as a test run and quality check for the overall data extraction process, which was subsequently carried out by the first author. The aim of the test run was to identify discrepancies in interpretation and reduce the incidence of errors. Most of the data was extracted and categorized using a predefined set of categories (see Appendix Tab. A5), minimizing typing errors and to facilitating subsequent statistical analysis.

3 Results

3.1 Which forms of citizen science projects exist worldwide for the ecological monitoring of rivers and streams?

A total of 87 citizen science river or stream monitoring projects were identified worldwide (see Appendix Tab. A7). The United States of America (US) accounts for the largest share, with 30 projects, followed by Canada with 14 projects. In Europe, 55 projects were recorded in total, with the United Kingdom (11 projects) hosting the highest number (Fig. 3). Of all projects, 5% operate on a global scale and 8% on an international scale.

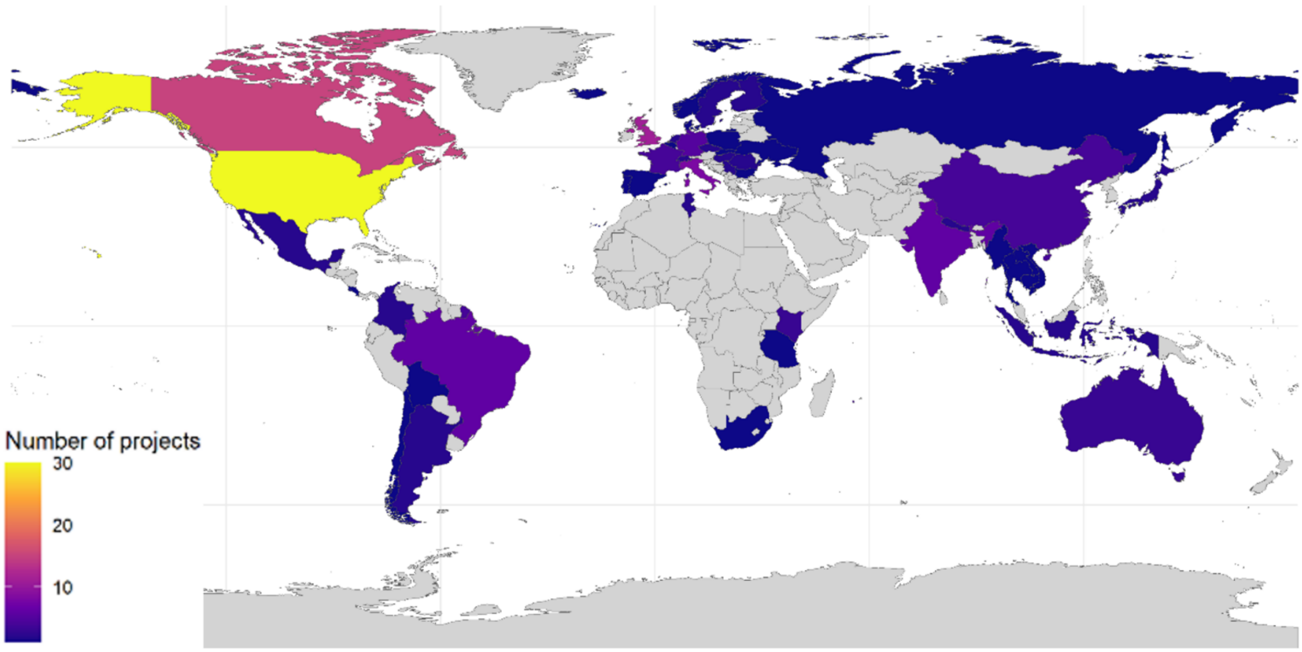


Figure 2- Distribution of the 87 identified citizen science stream monitoring projects worldwide (as described above). The color scale represents the number of identified projects by country, with the highest number shown in yellow and lowest in purple.

The longest-running project was active from 1912 to 2016. This community-driven initiative was conducted in the River Spey catchment in Scotland, where members of local angling clubs monitored water temperature and water levels (Pohle et al., 2019). Notably, 88% of the projects were initiated after 2000.

The number of participants varied considerably among projects. In some cases, the citizen science projects were still in development at the date of publication (e.g. Kielstra et al., 2019), resulting in relatively small participant groups. By contrast, large-scale projects such as the River Listening project involved more than 20,000 participants. In this project, citizen scientists used a non-invasive, custom-built mobile application to record and detect soniferous river species (Barclay et al., 2020).

Out of the 87 projects, 31 (36%) were based on or referred to official frameworks. For instance, 14% of all projects were associated with the Water Framework Directive, and 6% related to the Sustainable Development Goals.

Regarding the type of participation, a total of 41% of the projects were classified as contributory, meaning that citizen scientists were involved solely in data collection. Another 36% were collaborative projects, in which citizen scientists participated in additional steps, such as data analysis. The remaining 23% were co-created projects, where citizen scientists were engaged in all stages of the research process (Shirk et al., 2012) (see Appendix Fig. A2).

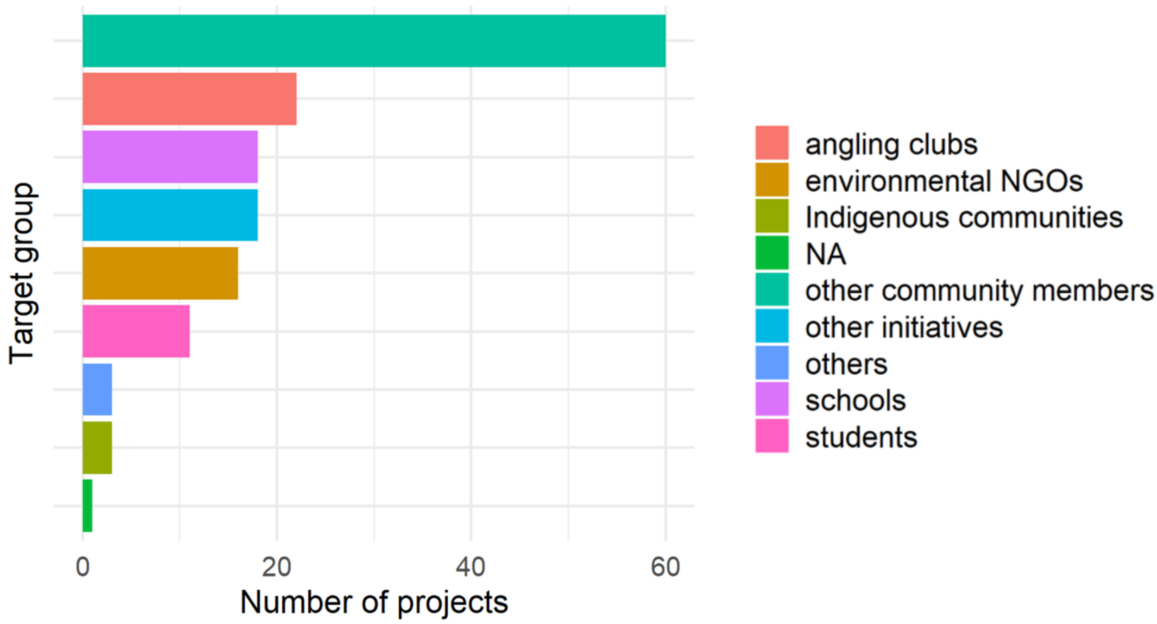


Figure 3 - Number of projects per target group. Target groups include angling clubs, environmental NGOs, Indigenous communities, other community members, other initiatives, schools, students, and others. NA indicates projects for which target groups were not explicitly mentioned. Projects involving multiple target groups were counted multiple times.

The largest citizen scientist target group consisted of community members, such as locals, residents and farmers, represented in 60 projects (69%). Other frequently involved groups included angling clubs (22 projects), schools (18 projects), and other local initiatives (18 projects). A few projects also collaborated with Indigenous communities (3 projects; Fig. 3).

In terms of diversity, 50 projects engaged only a single target group, while 3 projects involved as many as five different groups. Notably, university students and environmental NGOs were included exclusively in projects with multiple target groups (see Appendix Fig. A3).

Overall, 72% of the projects reported providing some form of citizen science training. This training was delivered in various ways, including online sessions (e.g., via Zoom), instructional videos and written guidelines, on-site preparation, or short courses conducted prior to monitoring activities. In contrast, 18% of the projects did not provide any formal training, often because they involved target groups such as angling clubs or Indigenous communities, which already possessed relevant expertise.

Regarding peer mentoring and learning, 61% of the projects did not mention any such activities. However, 18% explicitly included peer mentoring, frequently in combination with angling clubs or Indigenous communities. In some projects, peer mentoring was facilitated through the formation of subgroups, with certain individuals taking on leadership or coordination roles (see Appendix Fig. A5).

The following examples showcase well-designed and impactful citizen science projects. Each project is presented in an explanatory box to highlight the features that make it particularly successful or innovative.

Freshwater Watch (Box 1) is a citizen science project that creates a large global dataset, particularly focusing on water quality measurements from various parts of the world. It has established collaborations with the Riverfly Monitoring Initiative (Box 2) and MorpH (Box 3). The Riverfly Monitoring Initiative enables citizen scientists to detect and report pollution incidents by sampling macroinvertebrate taxa, while the MorpH survey allows for the assessment of the hydro-morphological status of rivers and streams. Together, these projects address key aspects of freshwater ecosystems and can be implemented globally.

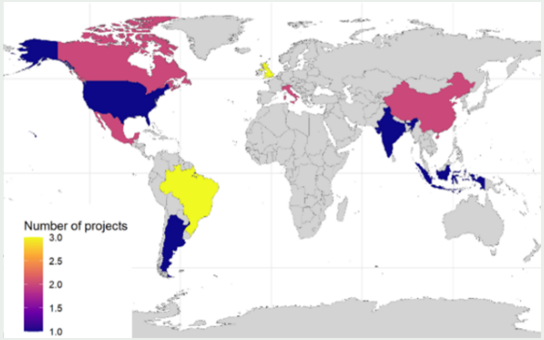
Moreover, the FLOW Project (Box 4) integrates hydro-morphological, water quality, and biological indicators, and provides training as well as expert data validation. The project is implemented across Germany and not only assesses the ecological status of rivers and streams but also investigates the impacts of citizen science participation on the citizens themselves (von Gönner et al. 2024).

To complement these larger network-oriented initiatives, the Musconetcong Watershed Association (Box 5) represents a more locally grounded and co-created approach, described by Field-Juma et al. (2021). This community-initiated monitoring programme emerged from local concern for the condition of the Musconetcong River in New Jersey (USA) and illustrates how participatory monitoring, local ecological knowledge, and community–scientist collaboration can jointly inform river management and restoration efforts.

Together, these examples demonstrate the diversity of citizen science in freshwater monitoring—from large-scale frameworks that link local observations into global datasets to community-based initiatives that foster local ownership, trust, and long-term environmental stewardship.

Box 1: FreshWater Watch
(https://www.freshwaterwatch.org/)

FreshWater Watch is a citizen science project developed by the environmental charity Earthwatch Europe in 2012. It is a centralised platform that enables citizen scientists to upload water quality data to a central database via a mobile application or an online form. The project involves more than 20,000 active participants worldwide. Indicators monitored include nutrient levels, land use, pollution sources, aquatic life, algae, and turbidity.



Distribution of the ten identified projects connected to Freshwater Watch. The colour scale represents the number of identified projects per country, with the highest number shown in yellow and the lowest in purple.

- → At least 10 projects identified in this review are connected to FreshWater Watch
- → More than 20,000 active citizen scientists involved
- → Centrally managed global database

For example, Castilla et al. (2015) used the platform to compare water quality data from streams, rivers, lakes and ponds across 13 cities: Boston, Buffalo and Chicago (USA); Buenos Aires (Argentina); Curitiba, São Paulo and Rio de Janeiro (Brazil); Delhi (India); Guangzhou and Hong Kong (China); Mexico D.F. (Mexico); Jakarta (Indonesia) and Vancouver (Canada).

Box 2: Riverfly Monitoring Initiative
(https://www.riverflies.org/), (Brooks et al., 2019)

The Riverfly Monitoring Initiative was established in 2007 by the Riverfly Partnership in the United Kingdom. The project empowers anglers and local communities to monitor rivers and streams, detect pollution incidents and communicate findings directly to relevant authorities.

The initiative focuses on macroinvertebrate taxa that are easy to identify and sensitive to pollution. In recent years, the project has expanded and is now linked to FreshWater Watch and MoRPh. This development enables citizen scientists to monitor not only biological indicators but also hydro-morphological and water quality parameters.

- → Detection of pollution incidents
- → Direct communication with local authorities based on pollution incidents identified through macroinvertebrate sampling
- → Collaborating with MoRPh and FreshWater Watch

Box 3: MoRPh (Modular River Survey)
(https://modularriversurvey.org/morph-rivers/)

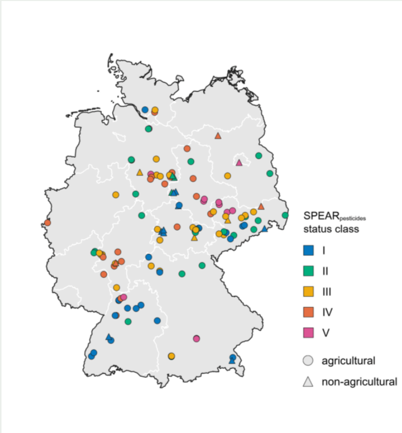
The MoRPh survey was established in the UK through a partnership between Cartographer Studios, Queen Mary University of London, and the Environment Agency in 2016-2017. It operates in close collaboration with the Riverfly Monitoring Initiative and enables citizen scientists to conduct detailed characterizations of river and stream habitats. as the survey supports the assessment of river conditions and the monitoring of changes over time. Moreover, it serves as a valuable tool for identifying human interventions and evaluating the success of river restoration measures.

→ Assessment of river and stream conditions
→ Identification of human interventions and evaluation of restoration measures

Box 4: FLOW project
(https://www.flow-projekt.de/index.php/en/), (e.g. von Gönner et al., 2024)

The FLOW project is a nationwide German citizen science initiative established by the Helmholtz-Centre for Environmental Research – UFZ, the University of Jena, and the German Centre for Integrative Biodiversity Research (iDiv), in collaboration with Friends of the Earth Germany (BUND) and the German Angling Association (DAFV). The project monitors small streams in Germany using three categories of indicators: hydro-morphology, water quality, and biological communities. Macroinvertebrates are used as bioindicators, and participants receive training, support and field equipment.

Since 2020, the project has involved over 1000 participants. Using the SPEARpesticides indicator on macroinvertebrate communities, it was shown that 58% of agricultural streams did not meet good ecological standards. In-depth method testing with official monitoring programs led to the development of an entry-level project in collaboration with national TV (#UnsereFlüsse), which further increased public engagement and visibility across Germany.



Map of Germany showing citizen science SPEAR$_{pesticides}$ (n=120). The symbols are coloured according to the ecological status class. Agricultural sites are shown as a dot, non-agricultural sites as a triangle.

→ Nationwide citizen science initiative for small stream monitoring in Germany
→ Provision of training, support, and field equipment for participants
→ In-depth method validation through comparison with official agency monitoring

Box 5: Musconetcong Watershed Association (MWA)
(https://www.musconetcong.org) (Field-Juma et al. 2021)

Founded in 1992, the Musconetcong Watershed Association (MWA) is a community-based initiative dedicated to protecting and restoring the Musconetcong River in New Jersey (USA). It engages local residents, scientists, and organizations in collaborative activities such as water quality and macroinvertebrate monitoring, educational programs, and river cleanups.

Citizen scientists are trained to collect and interpret ecological data that directly inform local management and restoration efforts. This shared monitoring process fosters scientific learning, transparency, and trust between community members and experts.

A key example of co-created action is the dam removal campaign launched in 2009, in which ecological data and local knowledge were combined to restore river flow while preserving cultural heritage

→ Demonstrates how participatory monitoring and locally adaptive collaboration strengthen trust, data acceptance, and long-term environmental stewardship.

3.2 Which methods and indicators are used to assess river hydro-morphology, chemical water quality and biological communities?

The majority of projects utilised standardized surveys (38%; Fig. 4), which often focused on evaluating river and habitat conditions or on surveying fish and other fauna. Standardized sampling kits were employed in 32% of projects, frequently in conjunction with the assessment of chemical parameters. Other projects involved the collection of biotic samples and taxonomic identification (24%), in which citizen scientists were tasked with collecting or capturing of macroinvertebrates, fish or other biotic communities for identification purposes. The least common approach involved the use of immobile gauges, where citizen scientists submitted data via an application or text message (7%).

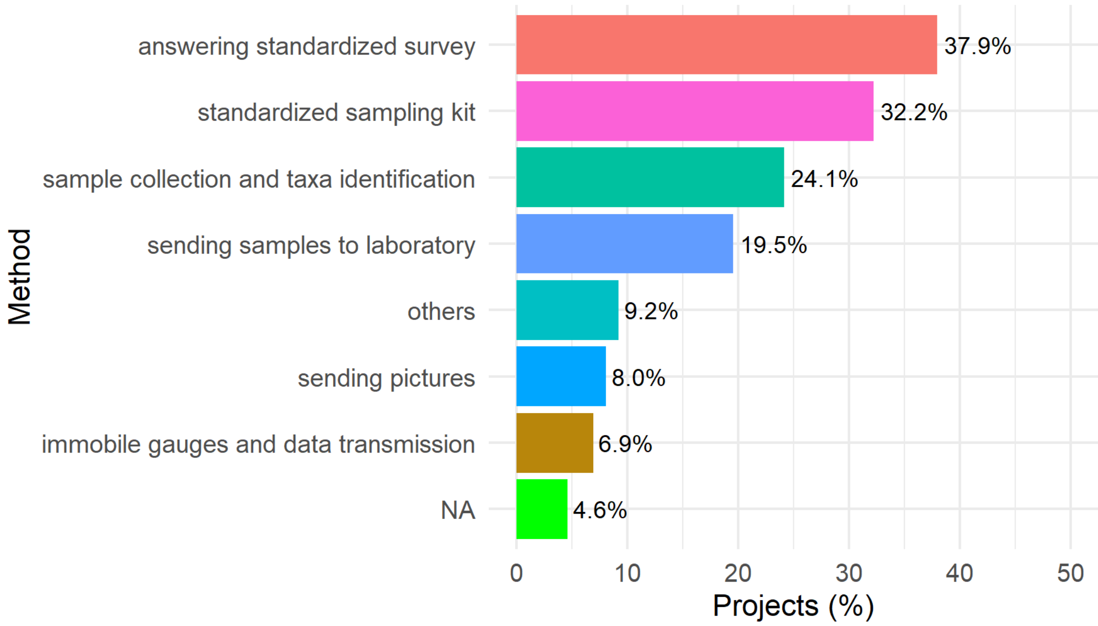


Figure 4 - Share of projects by method (%).NA indicates projects for which methods were not explicitly reported. Projects involving multiple methods were counted multiple times.

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A total of 19 projects (22%) employed two methods, while 9 projects (10%) utilised three methods. Among projects employing two methods, the most frequent combination was the use of standardized sampling kits in conjunction with standardized surveys. For projects employing three methods, the most common combination included the collection of biotic samples and taxonomic identification, together with standardized surveys assessing hydro-morphological parameters, and the use of chemical sampling kits. In contrast, the method involving immobile gauges and data transmission was never applied in combination with other methods (see Appendix Fig. A5).

The level of knowledge required from citizen scientists varied considerably across projects. In some cases, participants were expected to possess substantial expertise and were provided with training, for example in the collection of macroinvertebrate samples and taxonomic identification (von Gönner et al., 2024). In other cases, only minimal knowledge was needed, as participants could simply capture and upload photos using a mobile app designed for the project (e.g. Fehri et al., 2020).

Most of the identified citizen science projects used biological indicators (58.9%), followed by water quality (49.4%) and hydro-morphology (43.7%). More than one third of them applied indicators of multiple categories (Fig. 5).

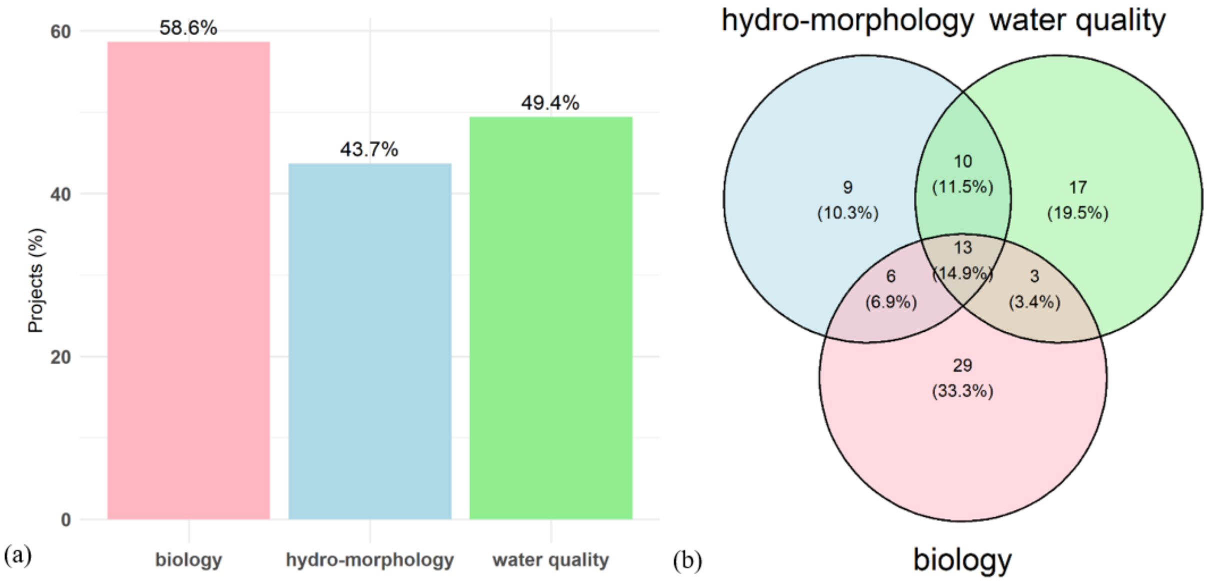

Figure 5 - Multiple categories of indicators used by the projects. (a) Overview by individual category. (b) Use of multiple categories of indicators within a single project. Overlapping circles indicate the number of projects employing multiple categories.

The most frequently used hydro-morphological indicator was stream flow, which included measurements of flow diversity, velocity, or discharge, and was applied in 21 projects (24%). The second most common indicator was sediment, monitored in 16 projects, focusing on sediment and substrate diversity. In total, more than 11 different hydro-morphological indicators were identified. These ranged from measures of human influence (e.g., land use, barriers/dams) to habitat structure and the physical conditions of water bodies (e.g., water level, flow velocity) (see Appendix Fig. A7).

Across the citizen science projects, more than eight different biological indicators were monitored. These included large aquatic fauna excluding fish, such as dolphins or muskrats (6 projects), fish, small aquatic organisms such as macroinvertebrates and plants (9 projects). The most frequently used biological indicators were macroinvertebrates (22 projects) and fish (20 projects), both commonly associated with sample collection and taxonomic identification (see Appendix Fig. A6).

The three most frequently used water quality indicators were nitrogen compounds (25 projects), phosphorus compounds (22 projects), and temperature (21 projects). Monitoring approaches varied widely, from simple visual assessments, such as evaluating water colour, to standardized procedures including the use of sampling kits or laboratory analyses to detect nitrogen and phosphorus contamination (see Appendix Fig. A8).

In 84% of the projects, some form of data quality control was implemented. Examples of these measures include expert validation, the use of control samples or automatic checks when samples were submitted to laboratories (Fig. 6).

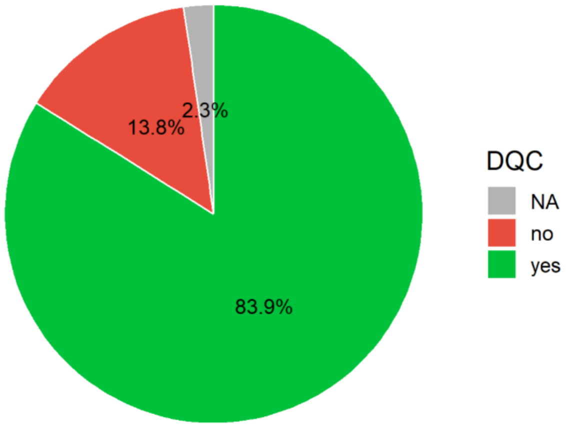

Figure 6: Share of projects that applied data quality control (DQC). NA indicates projects for which data quality control was not explicitly reported).

Quality assurance was often achieved through expert validation of citizen-collected data, for instance when participants submitted photos or when samples were analysed in a laboratory (e.g. Forrest et al., 2019; Molnár et al., 2024).

The accuracy of citizen science data increases when proper training is offered (Bonn et al., 2021). In total, 72% of the reviewed projects included training components, ranging from on-site to online sessions and instructional materials (e.g. Dwivedi, 2021; Loiselle et al., 2024; von Gönner et al., 2024). Additionally, 18% implemented peer-to-peer training approaches, where experienced citizen scientists acted as group leaders (e.g. von Gönner et al., 2024).

3.3 To what extent can the citizen science monitoring data be used to assess the ecological effects of restoration measures?

Overall, few examples were found in the literature where citizen science data were used to assess restoration effectiveness. Of the 87 projects identified, eight had implemented restoration measures (Table 6) and an additional seven projects were in the planning stage. Among the eight projects with implemented restoration measures, citizen science involvement varied both in scope and intensity. Two of these projects included practical restoration activities directly carried out by citizen scientists in addition to monitoring efforts (Clarke et al., 2023; Conallin et al., 2018). In the other cases, citizen scientists primarily contributed to data collection, for example by monitoring macroinvertebrates, riparian habitats, or fish populations. Three of the identified projects adopted a co-created design together with stakeholders (Clarke et al., 2023; Conallin et al., 2018; Oppenheimer et al., 2015), enabling stakeholders to support decision-making. A notable example of restoration monitoring is the case study by Edwards et al. (2018), in which students collected macroinvertebrate data before and after restoration measures were implemented (Box 5). This allowed the assessment of ecological impacts and facilitated comparison with a control stream.

Table 6 - Identified citizen science (CS) projects involving restoration activities and their level of CS involvement

Project name, Author and year	Restoration measures	Citizen science involvement
NA (Edwards et al., 2018)	→ Native riparian planting → Addition of logs, habitat boulders and pools	→ Before-and-after monitoring of macroinvertebrates
River Bure project (Clarke et al., 2023)	→ Habitat improvement	→ Co-created: designing a monitoring project to understand pressures on fish biodiversity → eDNA monitoring → small practical habitat improvements
Riverfly Monitoring Initiative (Brooks et al., 2019)	Yes (type not specified)	→ Riverfly plus: Before-and-after responses to river restoration → Detection of serious pollution incidents → Monitoring of macroinvertebrates
Dolores River Restoration Partnership (Oppenheimer et al., 2015)	→ Restoring of the riparian corridor: managing invasive plants → Increasing diversity and abundance of native riparian plants	→ Monitoring of riparian habitats → Co-created planning of restoration and monitoring projects
Musconetcong Watershed Association (Field-Juma & Roberts-Lawler, 2021)	→ Dam removal	→ Before-and-after dam removal monitoring → Macroinvertebrate monitoring and habitat information
Fish and Flow SAM project (Conallin et al., 2018)	→ Restocking of Murray cod → Delivery of fresh water after flooding events → Regulation of fishery	→ Co-created: citizen scientists involved in decision-making → Monitoring using anglers' data and electrofishing data of two native fish species
NA (Romer et al., 2024)	→ River channel habitat diversity improvement → Restoring connection of river channel to floodplain	→ Existing monitoring project: fish passage at dams → Assessing impacts of restoration efforts
The Thames European Eel project (Pecorelli et al., 2019)	→ Installing eel passages	→ Monitoring of eel populations → New funding for installation of eel passages secured

Box 5: Before-After-Control-Impact (BACI) of stream restoration: a citizen science case study

Edwards et al. (2018) describe a freshwater monitoring case study assessing the effects of restoration in the US.
Through a partnership between a county municipality, a high school, and a university, high school students were trained to collect macroinvertebrate data. This data was used to monitor conditions before and after restoration measures aimed at improving salmon-rearing habitat at Rock Creek (USA). Two streams were monitored: Balch Creek, serving as the control stream due to its minimal degradation, and Rock Creek, the restored stream. Citizen scientists collected data at Rock Creek prior to restoration (2010–2013) and after restoration (2014–2016). In total, 2,300 students participated in 25 sampling events.

Edwards et al. (2018) suggest that citizen science programs can contribute valuable data and increase citizens' awareness of restoration measures. Important steps include:

- → Training participants to collect macroinvertebrate data
- → Before-and-after monitoring of restoration measures

4 Discussion

4.1 Global distribution and development of citizen science stream monitoring projects

Citizen science is a powerful tool for monitoring, and globally many successful freshwater citizen science projects contribute to science, education and local action. Next to contributing to freshwater scientific research and monitoring and thereby providing valuable information for evidence-based management and conservation, the involvement of volunteers is also an important tool to develop a joint understanding, knowledge and civil participation (Turrini et al. 2018; von Gönner et al. 2023), raising public awareness of environmental issues and promoting a sense of stewardship for (local) ecosystems (Edwards et al., 2018). Ultimately, citizen science can create impact by not only collecting important data for monitoring, but also by enhancing a sense of self-efficacy and collective action for stream protection and conservation (von Gönner et al. 2024).

Most of the identified citizen science projects for stream and river monitoring were developed in Europe and North America. This demonstrates an **uneven geographic distribution**, with few or no projects in African and Central Asian countries. Similar patterns have been observed in other areas of monitoring and conservation management, which also show a disproportionate focus on **high-income countries** (Chapman et al., 2024). This imbalance likely reflects the historical legacies and might be linked to limited organisational capacity, insufficient infrastructure to support civil engagement, and a lack of history of democratic practices (Chapman et al., 2024; Pocock et al., 2019; Quinlivan et al., 2020). **Citizen science has expanded** significantly in the last two decades, especially within **EU member states**, largely due to the EU's active support of such initiatives (Bonn et al., 2021). However, this study includes only published articles. There are likely additional citizen science stream monitoring projects that exist beyond those represented in the peer-revied literature. Consequently, citizen science projects from the Global South may be underrepresented in this review (e.g. Walker et al., 2021).

The growth and distribution of citizen science projects in Europe may also be associated with the **Water Framework Directive** (WFD), implemented in 2000. Most of the identified projects were initiated **after 2000**. The WFD has been a key **driving force** for scientists, particularly in European countries (Copetti & Erba, 2024). Notably, 14% of the projects explicitly mentioned or were linked to the WFD. The highest number of European projects was found in the United Kingdom (UK), which may be related to the UK's long tradition of volunteering and natural history societies (Pocock et al, 2017; Preston et al., 2015).

The majority of identified citizen science projects originated in the United States (30 projects) and Canada (14 projects). **Government agencies** such as the U.S. Environmental Protection Agency (EPA) and the Environment and Climate Change Canada (ECCC) actively promote and **support community-based monitoring. Increasing public concern** about freshwater degradation has also contributed to the emergence of more **integrative projects** (ECCC, 2021, 2024; EPA, 1997). The two countries share numerous freshwater systems and policies aimed at protecting transboundary waters (IJC, 2016). However, no citizen science river or stream monitoring projects that were jointly developed by both countries were identified in this review.

Additionally, 8% of the projects operated on an international scale, while 5% were conducted globally. For example, the Plastic Cup Project operates across five countries - Hungary, Ukraine, Romania, Serbia, and Slovakia – within the shared catchment of the river Tisza. The project involves citizen scientists in reporting riverine litter accumulation (Molnár et al., 2024).

4.2 Indicators and methods used in citizen science stream monitoring

The ecological status of freshwater ecosystems is commonly assessed using physicochemical, hydro-morphological, and biological quality elements (European Commission, 2000). Since the implementation of the WFD, monitoring approaches have shifted from a sole focus on chemical water quality towards more holistic assessments that include biological and hydro-morphological components (Moss, 2007). Our analysis revealed that most citizen science projects monitor biological indicators (59%), roughly one in seven studies (15%) also encompassing hydro-morphological and water quality indicators. Macroinvertebrates (25%) were the preferred biological indicators – particularly Ephemeroptera, Plecoptera, and Trichoptera **(EPT) taxa** – as they provide reliable information on habitat degradation (Waite et al., 2010). Sampling macroinvertebrates is relatively simple and inexpensive compared to water chemistry sampling (Wiedemann, 2006), but it requires taxonomic expertise. Therefore, appropriate training must be provided to citizen scientists to ensure accurate

taxa identification (Nerbonne & Vondracek, 2003). In addition, subsamples should be quality-checked by coordinating scientists to assess the data accuracy (von Gönner et al., 2023).

Several macroinvertebrate monitoring projects collaborated with local environment groups and **anglers** (e.g. von Gönner et al., 2023). In our review, 22 projects (25%) involved angling clubs as their main target group. Such collaborations benefit from anglers' strong organizational networks and high motivation (Williams et al., 2016).

Fish were also frequently used as indicators (23%). **Fish** species are particularly sensitive to pollution, and as migratory organisms they serve as effective indicators of **habitat connectivity** and fragmentation (Chovanec et al., 2002; Yarsan & Yipe, 2013). However, fish-based monitoring has drawbacks, including the influence of fish mobility and the need for specialized sampling techniques (Figueroa et al., 2003). Many projects focused on individual fish species, using photos, surveys or catch records (e.g. Briggs et al., 2020; Nelson et al., 2013; Renjithkumar & Roshni, 2024; Tsuboi et al., 2024).

Plants (10%) were another commonly monitored indicator, particularly for detecting **invasive species**. For instance, Garretson et al. (2022) described a project where citizen scientists estimated the abundance of invasive plant species. The link between invasive plants, human alteration, and **land use change** has been demonstrated in several studies (e.g. Vakhlamova et al., 2014; Williams et al., 2009). Land use itself was also monitored as an indicator in several citizen science projects (14%).

The most frequently used hydro-morphological indicator was **stream flow** (24%). Stream flow affects riverbank erosion, sedimentation, and riparian vegetation, thereby shaping **habitat heterogeneity** (Florsheim et al., 2008). **Riparian zones, which form the transition** between terrestrial and aquatic ecosystems, play an essential role in shading and cooling water bodies, stabilizing riverbanks, and transferring organic and inorganic material that sustains aquatic food webs (Nilsson, 1992; Nilsson & Svedmark, 2002). These hydro-morphological indicators were often assessed using standardized surveys (e.g. von Gönner et al., 2024). Because hydro-morphological parameters vary seasonally, repeated measurements at the same site and season are necessary (Storey et al., 2016a).

Water level and temperature were also frequently monitored using simple tools such as immobile gauges or thermometers (e.g. Avellaneda et al., 2020; Lowry et al., 2019). Water temperature (24%) was one of the most common water quality indicators, along with **nitrogen** (29%) and **phosphorus** compounds (25%). **Agricultural runoff** contributes to nutrient enrichment, with nitrogen and phosphorus being of particular concern (Drechsel, 2023). Elevated nutrient concentrations and rising water temperatures can exacerbate eutrophication (Reid et al., 2019; Woodward et al., 2010). Measuring temperature is a relatively straightforward process. For example, the longest-running citizen science project measured water temperature from 1912 to 2016 in collaboration with anglers (Pohle et al., 2019).

Other projects monitored **turbidity or water colour** (together 24 projects), both of which serve as reliable measures for water quality and contamination (Bachmann et al., 2002; Castilla et al., 2015; Lottig et al., 2014). However, chemistry indicators, except for water temperature, showed weaker correlations with expert data in some studies (von Gönner et al., 2023). Therefore, citizen science test kits should be **user-friendly and standardized** to minimize measurement errors (WFD, SDG 6.3.2). Because water chemistry fluctuates seasonally (e.g., after rainfall events) and multiple sampling events are required to obtain valid results.

Several authors have argued that traditional chemical tests alone are not insufficient to detect real-time **toxic events** and recommend combining them with biological monitoring (Long et al., 2000; van der Schalie et al., 2001). Several projects (15%), such as the FLOW project in Germany, the StreamSmart Citizen Science Program in the United States or the MAIV project in Portugal (Grantz et al, 2023; Pinto et al, 2020; von Gönner et al, 2024) integrated all three categories of indicators. The **FreshWater Watch** program, in connection with **MorpH**, also includes hydro-morphological, chemical and biological indicators, generating globally **comparable data**. Projects using this platform benefit from established structures for recruiting and training citizen scientists, as well as validated data submission protocols (e.g. McGoff et al., 2017; Sanna et al., 2024). The FreshWater Watch framework may enable countries without established citizen science programs to adopt these standardized tools and help bridge the monitoring data gap identified in section 4.1.

4.3 Citizen science data quality and technological advances

Data quality is essential to reliably base management decisions on citizen science and other research-derived data. This is particularly important for authorities, when data might be incorporated into official reporting. Therefore, data quality control is crucial - as in any scientific project - and can occur before, during, or after sampling. Measures to ensure quality control include sound project and survey design, training, supervision and guidance (on-site or online), adequate technical infrastructure and equipment, and sample or data verification following site visits (Herrmann et al., 2025).

Protocols of citizen science monitoring projects should be kept simple to maximize **data reliability** (Penrose & Call, 1995). Several case studies showed that when proper protocols are followed, citizen scientists can collect data with same accuracy as experts (Storey et al., 2016b). Overall, 84% of the projects applied some form of data quality control.

Some citizen science projects used immobile stream gauges maintained by participants, who were responsible for recording and transmitting data via apps or text messages. These initiatives demonstrate innovative approaches to ensure data accuracy (e.g. Oviedo-Vargas et al., 2024; Weeser et al., 2021). **Advances in technology -** such as mobile applications and the increasing availability of robust, simple, and inexpensive sensors - offer new opportunities, especially in data-scarce regions (Buytaert et al., 2014; Zheng et al., 2017). Such tools could also facilitate data sharing via **online platforms**, improving **accessibility and transparency**. For example, the project Together4Water uses an app to collect river discharge information during hydrological events in northern Tunisia (Fehri et al., 2020).

The emergence of novel technologies, combined with training and peer learning, represents a promising approach to enhance data accuracy. Some projects have used **eDNA methods** or electrofishing to validate citizen science data (e.g. Clarke et al., 2023). Furthermore, with the increasing availability of AI-assisted image classification tools, there is promising potential to further support macroinvertebrate identification (Simović et al., 2024). However, to reach the full potential of these efforts, citizen science data must be recognised and accepted by scientists and institutions. Without broader institutional acceptance, the potential of citizen science data remains limited and cannot adequately address existing data gaps. This is particularly relevant in the context of ecosystem restoration, where reliable monitoring data are essential for assessing the success of restoration measures (Bischof et al., 2025; Bonn et al., 2021).

4.4 Social and educational impacts of citizen science

As previously stated, the development of some citizen science projects has been precipitated by the rise of public concern regarding ecosystem degradation (4.1). The integration of communities in citizen science projects provides opportunities to understand and integrate **local expertise**, needs and interests. The data indicates that 41% of the project were contributory, 36% were collaborative, and 23% of co-created nature, meaning that only in some projects citizen scientists were included in all stages of the scientific process. The concept of co-creation has been demonstrated to be a significant factor in the **empowerment of the community** and the **democratisation of science**. Participatory processes have been demonstrated to facilitate a sense of collective ownership over scientific practices, thereby fostering renewed trust in the scientific community among the public (Bonn et al., 2021; Bruckermann et al., 2021; Pearson et al., 2010).

Some studies in this review report positive effects of participating and interaction with scientists, by **increasing environmental knowledge and awareness**, and a sense of responsibility towards nature. Eighteen projects worked with schools, raising environmental awareness from a young age. By engaging directly in scientific processes, students not only gain a better understanding of ecological systems but also experience science as an open, **participatory activity** rather than an exclusive domain of experts (Bonn et al., 2021; Bonney et al., 2009; Edwards et al., 2018; Shirk et al., 2012; Turrini et al., 2018).

Other projects included **Indigenous communities** (3 projects). Indigenous peoples share a sacred connection with the land and water, and knowledge of their surrounding environment is shared over generations. Integrating Indigenous and Western scientific approaches contributes to a more holistic understanding of ecosystems and represents an important step towards **decolonizing science**. Such an approach promotes mutual respect, knowledge co-production, and culturally grounded environmental solutions. Moreover, it can strengthen social resilience with Indigenous and local communities by **reinforcing cultural identity**, self-determination and participation in **decision-making processes** related to their environment (ECCC, 2024; Wilson et al., 2018).

The reliance on technological tools and other factors may unintentionally lead to exclusion, especially in regions with limited access to such resources. Therefore, citizen science projects must be **adapted to the historical, political, and epistemic context** in which they are implemented. Structures and methods developed in the Global North are not always suitable for the Global South. Participatory processes can also become biased if the representation and influence of different stakeholder groups are unbalanced (Sula, 2016; Walker et al., 2021). It has been poised by other authors that the demographic of participants in citizen science projects is predominantly composed of individuals from academic and middle-class backgrounds. It is therefore crucial to ensure the **inclusion of all relevant stakeholders** affected by monitoring, restoration or conservation measures, in order to achieve equitable participation and strengthen both social and environmental resilience (Bischof et al., 2025; Bonn et al., 2021).

4.5 Citizen science in restoration monitoring

The goal of the Water Framework Directive is to restore and maintain a good ecological status of freshwater systems, with detailed implementation guidelines provided (European Commission, 2000).

Birk and colleagues (2025) found that most river restoration measures are related to morphological and hydrological improvements. But good ecological status can be **difficult to achieve** and functional recovery can take an average of 10-20 years (Jones & Schmitz, 2009).

Despite the widespread implementation of restoration measures, the effectiveness of instream habitat restoration to enhance the biological richness **remains unclear** (Miller et al., 2010). Moreover, many restoration projects lack systematic monitoring, even though **before and after restoration assessments are essential** to understand the ecological impacts of such interventions (Bernhardt & Palmer, 2011; Feld et al., 2011; Morandi et al., 2014).

Edwards et al. (2018) and Field-Juma & Roberts-Lawler (2021) showed that citizen scientists can have a big impact on monitoring the before and after of restoration practices, particularly through data collection using macroinvertebrates as biological indicator. This suggests that other already existing citizen science programs using macroinvertebrates as their biological indicator, could perform restoration monitoring, without changing their project structure.

For example, the Riverfly Monitoring Initiative uses **sensitive macroinvertebrate taxa** to **detect pollution sources.** Sampling macroinvertebrates was applied not only to detect pollution incidents but also **empower the local community** to inform the authorities (Brooks et al., 2019). Another citizen science project, WAVE, also used macroinvertebrates as indicators and used the collected data to successfully achieve a **stream's protection** (Onion et al., 2023).

The responses of fish to restoration efforts are commonly used to measure ecological responses (Lester et al., 2007; Muotka & Laasonen, 2002; Rosi-Marshall et al., 2006). Due to their migratory characteristics, fish are particularly suitable for evaluating habitat connectivity and restoration success. For example, an existing citizen science monitoring project at the McKenzie River tagged fish to **monitor a fish dam passage** and successfully detected behavioural changes after upstream restoration measures (Romer et al., 2024).

Another valuable biological indicator for assessing and guiding restoration activities, is monitoring presence and spread of invasive plants. The Dolores River Restoration Partnership monitors the riparian habitat and monitors and manages **invasive plant control** and offers a prime example of citizen science project co-creation: a group of stakeholders spotted one invasive plant species and initiated a monitoring and restoration program (Oppenheimer et al., 2015).

Three of the identified projects adopted a **co-created design** together with stakeholders (Clarke et al., 2023; Conallin et al., 2018; Oppenheimer et al., 2015), enabling stakeholders to participate in **decision-making**. However, only two of these projects included practical restoration activities directly implemented by citizen scientists in addition to monitoring. For example, the River Bure project in the UK included **small habitat improvement measures** implemented by citizen scientists (Clarke et al., 2023). The Fish and Flow SAM project focused on restocking fish populations and delivered fresh water after flood events (Conallin et al., 2018). Both projects implemented completely different restoration measures, based on the specific needs and motivations of stakeholders and **adaptive** to the conditions of the monitored freshwater ecosystem.

Our review highlights **diverse citizen science initiatives in freshwater monitoring**, from global networks to locally co-created projects. Beyond summarizing individual studies, it is important to consider citizen science more broadly. It enables large-scale **data collection**, fosters **environmental awareness** and engagement, and can integrate **local knowledge**, particularly in participatory projects. Citizen science has the potential to **complement official monitoring** programs, leverage new technologies, and foster collaboration between scientists, communities, and policymakers. However, it should be considered that **data quality** and **representativeness** can vary (inconsistent data collection and overestimating the reliability of citizen-generated data if not carefully managed), **long-term participation** may be **challenging** (risks include volunteer burnout), and sustainability often depends on funding and institutional support. Thus, citizen science offers significant **benefits for research and community engagement** but is **not a universal solution**. Context-sensitive project design, training, and quality control are essential to maximize its impact on freshwater monitoring and restoration.

5 Synthesis and outlook

Citizen science is widely used in freshwater monitoring and restoration, enabling large-scale data collection, **raising awareness** of ecosystem degradation, and **empowering local communities** to participate in environmental **decision-making**. It also supports the integration of local knowledge into management, fosters stakeholder engagement, and can bridge science and policy.

However, projects vary in scope, objectives, and degree of citizen involvement. Each freshwater ecosystem and restoration project is unique, influenced not only by the ecological differences, but also **by local social and cultural contexts**. Therefore, citizen science projects should be adaptive to the local community, leveraging local knowledges and integrating already existing initiatives and local angling clubs or Indigenous communities. **Data quality, representativeness, and long-term participation** remain key challenges.

This study demonstrated that a wide variety of citizen science monitoring projects on rivers and streams exist. Most initiatives are located in the Global North, and few are directly linked to restoration measures. Ensuring stakeholder trust and social relevance is essential for project success. These projects differ substantially in their objectives and degree of citizen involvement. While some initiatives engage volunteers primarily to collect data and answer scientific questions, others are designed as tools for **environmental education**, awareness raising, and **community empowerment**. Overall, citizen science can bridge data gaps in restoration monitoring, provided that **standardized methods and strong partnerships** are established.

One of the main challenges for future citizen science initiatives is to better **integrate all relevant stakeholders** connected to the monitored freshwater systems, including local communities, decision-makers, and scientists, to ensure both data quality and social relevance. The **trust from science and policy** in citizen science data is essential for successfulness of citizen science programs.

Future projects should prioritize **adaptive, co-created designs**, integrating local communities, decision-makers, and scientists. Leveraging existing methods, tools, and data-sharing infrastructures can **improve interoperability and global connectivity**. Linking monitoring with tangible restoration actions can enhance motivation, demonstrate impact, and strengthen long-term sustainability. Collaborative and co-created project designs not only engage citizen scientists but also empower them to take ownership of the monitoring and management process with at least **small-scale restoration measures**. Technological innovations offer further opportunities, but must be applied with attention to local ecological, social, and historical contexts.

Citizen science monitoring has been demonstrated to be a valuable tool in filling in existing data gaps and identifying deficiencies in stream conditions. Furthermore, it has been shown to have the potential for **long-term data collection**, supporting the monitoring and assessment of freshwater restoration beyond the lifetimes of academic research projects. The implementation of restoration measures invariably results in a modification of the landscape, and it is important to note that this change may not be universally welcomed. The monitoring of the local river and streams by citizen scientists has been demonstrated to increase the likelihood of **stakeholders taking action** and understanding the need to implement measures for the restoration of the ecosystems. Low-cost restoration measures to diversify stream morphology and to improve their ecology have the potential to act as a tool to encourage participation and to empower individuals (Bischof et al., 2025).

Overall, citizen science in freshwater monitoring is evolving from isolated data collection efforts toward more **integrated, participatory, and action-oriented approaches** that can bridge science, policy, and local communities. When carefully designed, citizen science provides a powerful tool to support healthy rivers, informed decision-making, and long-term environmental stewardship.

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7 Appendix

Table A1 - Used search strings on different platforms

Plattform	Search String	Number
Web of Science	(TS=(“stream restoration*“)) AND TS=("citizen science")	7
Web of Science	(TS=(“stream restoration*“)) and TS=(participation)	17
Web of Science	(TS=("river restoration")) AND TS=(participation)	77
Web of Science	(TS=("river restoration")) AND TS=("citizen science")	18
Web of Science	(TS=("stream")) AND TS=("citizen science")	121
Web of Science	(TS=("stream monitoring")) AND TS=("citizen science")	12
Scopus	(TITLE-ABS-KEY ("citizen science")) AND (TITLE-ABS-KEY ("stream restoration"))	2
Scopus	(TITLE-ABS-KEY ("citizen science")) AND (TITLE-ABS-KEY ("river restoration"))	11
Web of Science	(TS=("river")) AND TS=("citizen science")	381
Web of Science	(((TS=(stream)) AND TS=(restoration)) AND TS=(citizen science))	38
Web of Science	(((TS=(stream)) AND TS=(restoration)) AND TS=(volunteer))	21
Web of Science	(((TS=(stream)) AND TS=(restoration)) AND TS=(participation))	64
Web of Science	(TS=(stream)OR TS=(river)) AND TS=(rehabilitation) AND (TS=("citizen science") OR TS=("volunteer") OR TS=(participation))	72
Web of Science	(TS=(stream)OR TS=(river)) AND TS=(regeneration) AND (TS=("citizen science") OR TS=("volunteer") OR TS=(participation))	40

Table A2 - Number of abstracts excluded based on exclusion criteria during the final abstract screening

Exclusion criteria	Number excluded
Study is not an article or review	11
Study is not about running waters	486
Study is not about monitoring project	56
Study doesn't assess ecological parameters	15
Study doesn't include citizen science	84
Study doesn't report applied citizen science	8
Study doesn't describe an existing project	15
Total excluded	675

Table A3 - Number of full texts excluded based on exclusion criteria during the final abstract screening

Exclusion criteria	Number excluded
Study is not an article or review	0
Study is not about running waters	15
Study is not about monitoring project	14
Study doesn't assess ecological parameters	2
Study doesn't include citizen science	26
Study doesn't report applied citizen science	4
Study doesn't describe an existing project	7
Study is reporting extractable DATA	16
Total excluded	84

Table A4 - Overview of the information extracted from each of the 85 reviewed papers, illustrated with one example

Recorded information	Example
Study title	A unique role for citizen science in ecological restoration: a case study in streams
Year	2018
First author	Edwards et al.
Journal	Restoration Ecology
Name of linked CS project	NA
Project duration in years	7
Project start-end (years)	2010-2016
Country	USA
Location coordination	Western Oregon, Clackamas river basin
Project lead	Research institute
Spatial scale	Regional
Type of waterbody	Stream
Standardised protocols	NA
Indicator hydromorphology – if yes which	No
Indicator water quality – if yes which	No
Indicator biology – if yes which	Yes - invertebrates
Methods	Sample collection and taxa identification
Participants prior knowledge	None
Participant target group	Schools
CS training	Yes
Peer learning/mentoring	No
Number of participants	2300
Monitoring frequency	Every half a year
Data quality control	No
Type of data quality control	-
Data availability	NA
Type of participation	Collaborative
Participant outcome	Skill and knowledge acquisition
Link to monitoring framework	NA
Scientific output	Scientific article
Restoration activity	Yes

Table A5 – Predefined set of categories used for the text analysis

Recorded information	Predefined set of categories
Project lead	Research institute, NGO, Community, Agency, Government, Other
Spatial scale	Global, International, Regional
Type of waterbody	Stream, River, Stream and river, Stream and lake, River and lake, Stream and river and lake
Standardised protocol	Yes/No/NA
Indicator: hydromorphology	Yes/No; Detailed description: see Appendix Tab. A7
Indicator: water quality	Yes/No; Detailed description: see Appendix Tab. A8
Indicator: biology	Yes/No; Detailed description: see Appendix Tab. A6
Methods	Standardized sampling kit, Gauges and App, Sending pictures, Sending samples to laboratory, Sample collection and taxa identification, Answering standardized survey
Participant prior knowledge	None, Newcomer, Experienced, Amateur experts
Participant target group	Schools, Universities, Angling clubs, NGOs, Indigenous communities, Other initiatives, Community members (locals, residents, farmers).
CS training	Yes-onsite, Yes-online, No
Peer learning/mentoring	Yes/No
Monitoring frequency	Yearly, Every half a year, Monthly, Weekly, Daily, Others
Type of participation	Contributory, Collaborative, Co-Created
Participant outcome	Knowledge acquisition, Skill acquisition, Community building, Others
Link to monitoring framework	SDGs, WFD, National framework, Other
Restoration activity	Yes/No, Planned

Table A6 - Detailed description of indicators for biological monitoring

Indicator used for statistical analysis	Specific taxa/examples (number of projects)
Algae	Algae (7)
Invertebrates	Invertebrates (21), Aquatic insects (1)
Bats	Bats (1)
Aquatic fauna	Caimans (1), Dolphins (1), Muskrats (1), Platypus (1), Stingrays (1), Terrapins (1)
Birds	Birds (1)
Plants	Plants (8), Lichen (1)
Fish	Fish (20)
Eel	Eels (2)
Others	Biofilm (1), Decapods (1), Soniferous species (1), Phytoplankton (1), Snapping shrimp (1), Others (1)

Table A7 - Detailed description of indicators for hydromorphological monitoring

Indicator used for statistical analysis	Specific indicators (number of projects)
Bank structure	Bank diversity (1), Bank stability (1), Bank structure (2)
Barriers/Dams	Barriers/dams (1), Dams (1)
Flow	Flow (7), Flow diversity (7), Flow features (1), Channel flow (1), Discharge (1), Flow velocity (1)
Land use	Land use (11), Settlement (1)
Meandering of watercourse	Meandering of watercourse (1), Channel alteration (1)
Pollution sources	Outfalls (1), Pollution (1), Pollution sources (1), Potential pollution (1)
Riparian vegetation	Riparian vegetation (11), Riparian vegetative tone width (1), Vegetation (1), Vegetative protection (1)
Velocity	Velocity (3)
Water level	Water level (14)
Width	Width (1), Channel dimensions (1)
Stream sediment	Sediment (1), Sediment deposition (1), Siltation coverage (1), Substrate diversity (8), Stream sediment (1), Diversity of sediments (1), Embeddedness (1), Epifaunal substrate (1), Bed habitat structure (1)
Others	Riverine profile (1), Frequency of riffles (1), Habitat (1), Erosion (1), Others (2)

Table A8 - Detailed description of indicators for water quality monitoring

Indicator used for statistical analysis	Specific measures (number of projects)
Chlorophyll-a	Chlorophyll-a (3)
Colour	Colour (5), Water colour (2)
Conductivity	Conductivity (11), Electrical conductivity (1), Specific conductivity (1), EC (1)
Dissolved oxygen	Dissolved oxygen (9)
Fecal coliforms	Faecal coliform bacteria (1), Faecal coliforms (1), Total coliforms (1)
Macro- or microplastic	Macroplastics (2), Microplastics (1)
Nitrogen compounds	Nitrate (14), Nitrate & nitrite-N (2), Nitrite (1), Total nitrogen (2), N-NH (1), NO_3-NO_2 (1), NH_3/NH_4^+ (4)
pH	pH (15)
pesticides	Pesticides (1), Glyphosate (1), Herbicides (1)
Phosphorus compounds	Phosphate (13), Phosphate-P (1), Phosphorus (2), Orthophosphate (2), P-PO (1), Total phosphorus (3)
Temperature	Temperature (20), Water temperature (1)
Total suspended solids	Total suspended solids (9), Total dissolved solids (4)
Turbidity	Turbidity (16), Nephelometric turbidity (1)
Others	Ca (1), E. coli (1), Mg (1), REFs (1), Alkalinity (1), Chloride (1), Decomposition rate (1), Dissolved greenhouse gas (1), Dissolved organic carbon (2), Dissolved silica (1), Fungal growth (1), Hardness (2), Major ions (1), Nutrients (1), Strontium water signatures (1), Suspended sediments concentrations (1), Trace metals (1), Others (2)

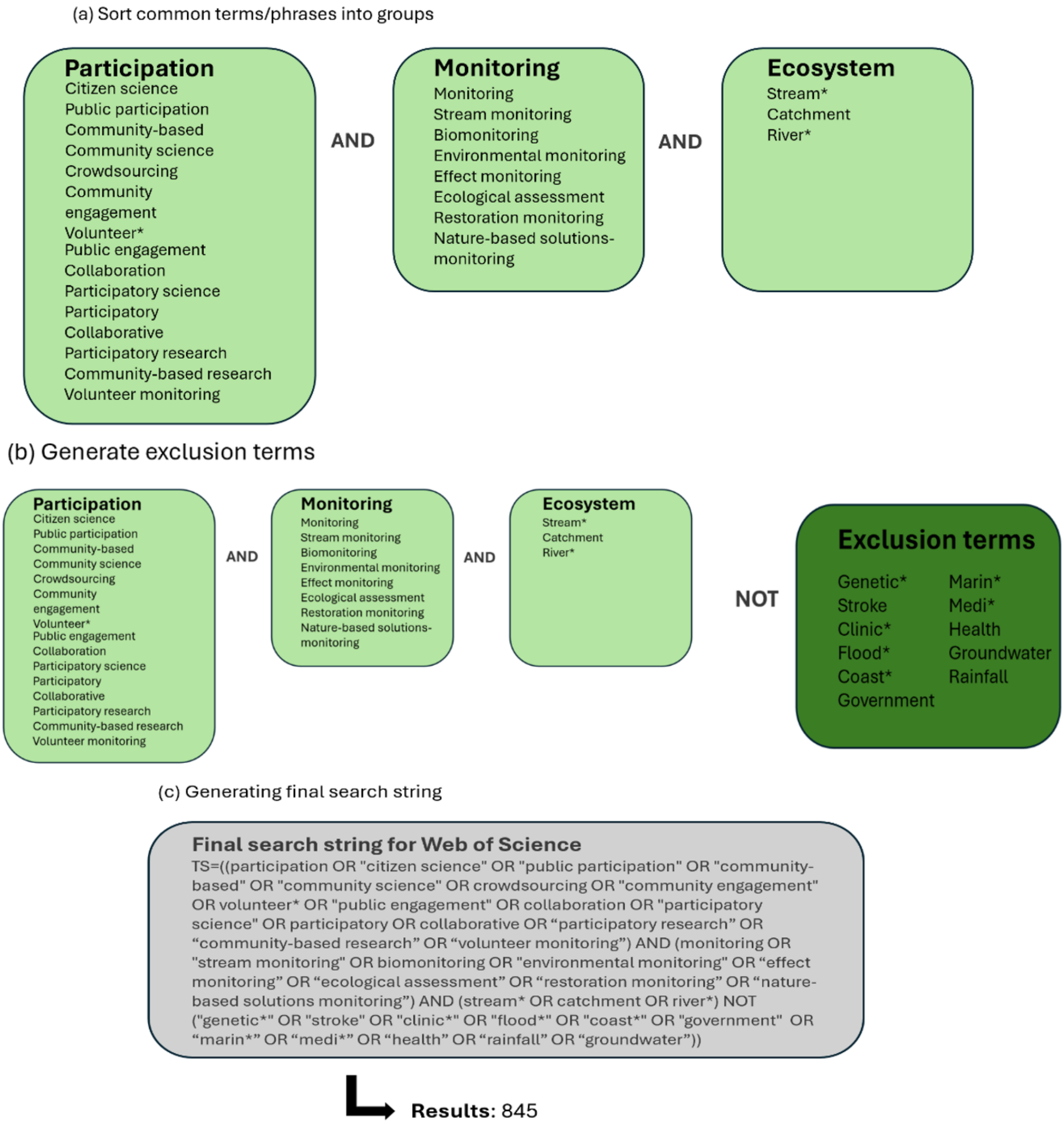

Figure A1 - Process of generating the final search string. From (a): Step 1, to sort the common terms and phrases into groups and find synonyms. (b): Step 2 is to find and define exclusion terms. And (c): Step 3, is to generate the final search string and to adapt it to the search platform Web of Science.

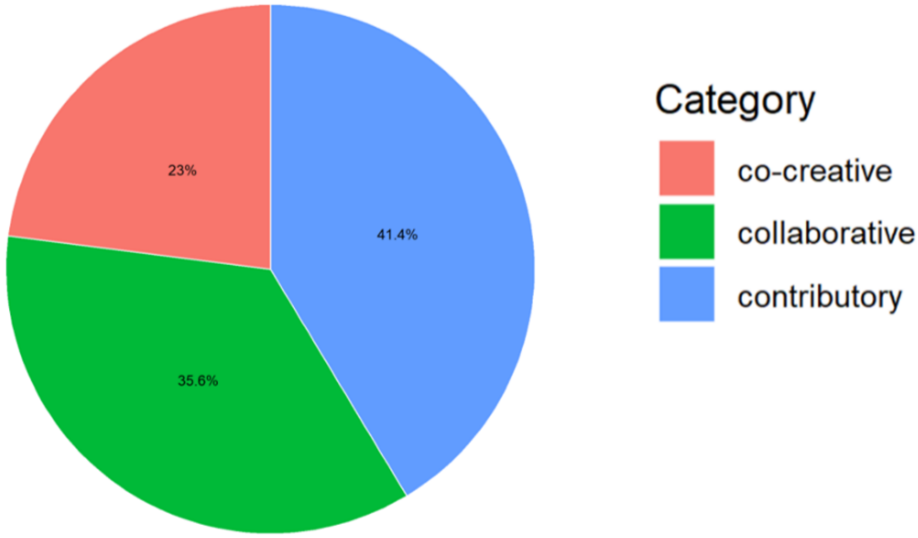

Figure A2 - Type of participation across projects (n=87). Categorization according to Shirk et al. 2012: contributory, collaborative, co-created.

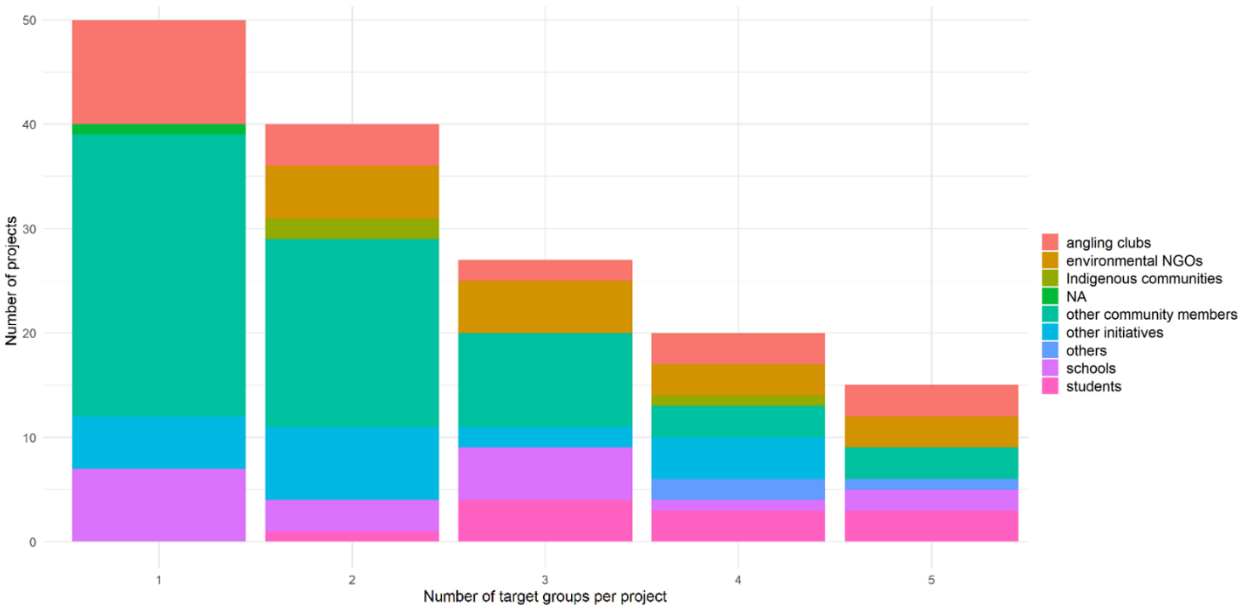

Figure A3 - Number of projects by target groups involvement. Target groups include angling clubs, environmental NGO, Indigenous communities, other community members, other initiatives, schools, students, others. NA: projects with no explicitly mentioned target group.

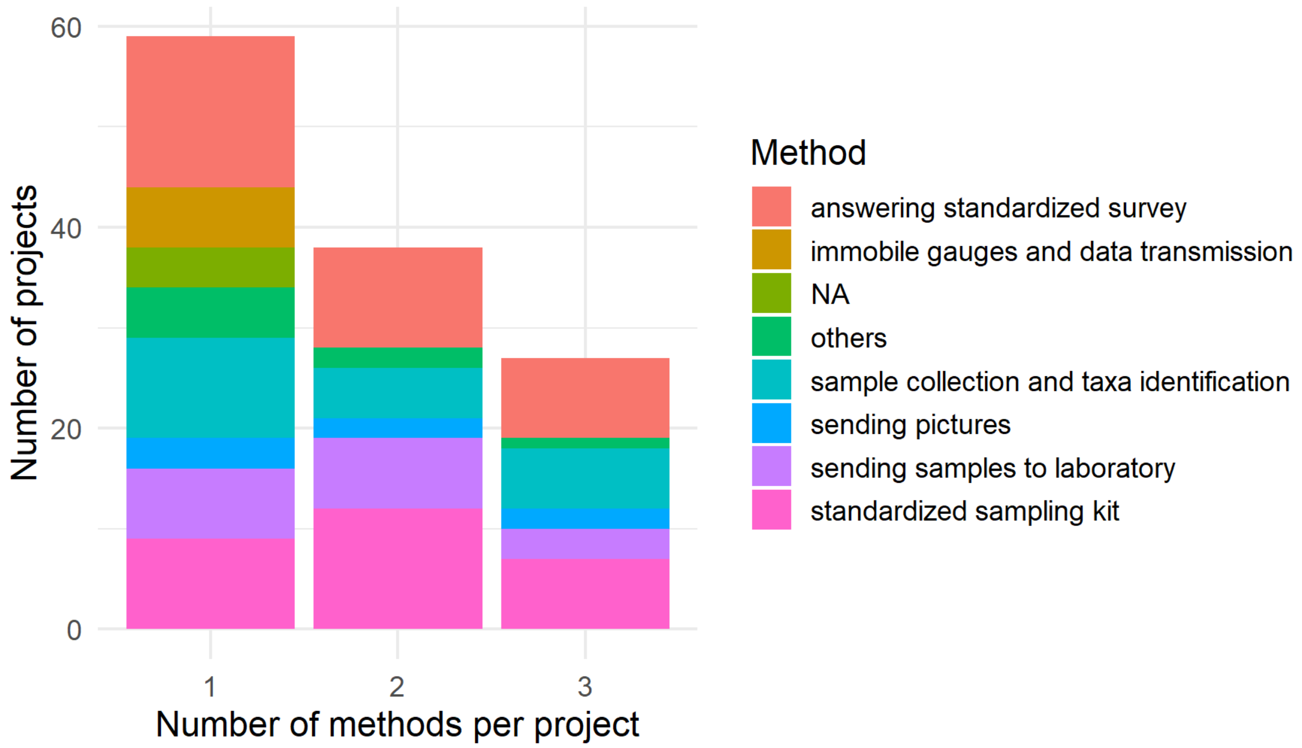

Figure A4 - Projects by number of methods and their combination. Methods include answering standardized survey, standardized sampling kit, sample collection and taxa identification, sending samples to laboratory, sending pictures, immobile gauges and data transmission, others. NA: projects with no explicitly mentioned method.

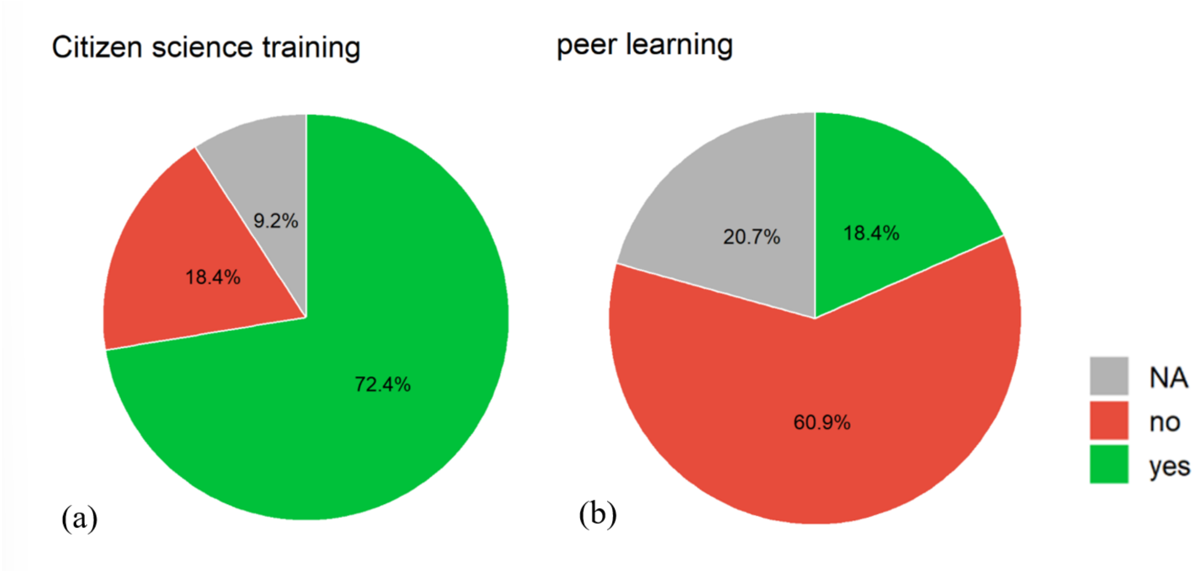

Figure A5 - Share of projects (a) providing citizen science training and (b) including peer learning/or mentoring. NA indicates projects where training or peer learning were not explicitly mentioned.

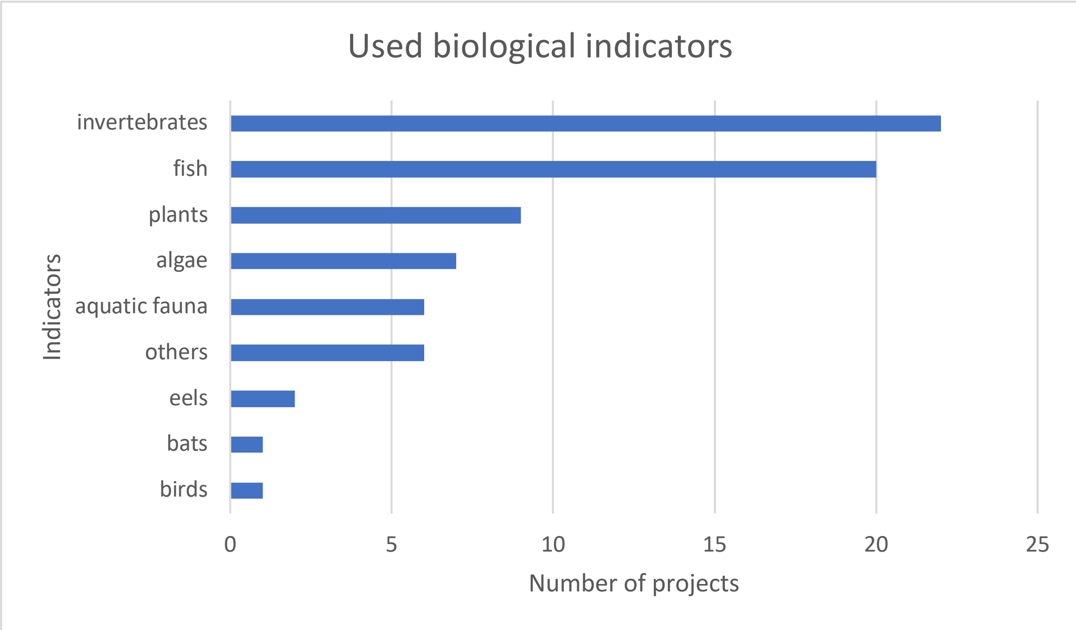

Figure A6 - Used biological indicators by number of projects. With indicators: invertebrates, fish, plants, algae, aquatic fauna, eels, bats, birds and others (more details see Tab. A1).

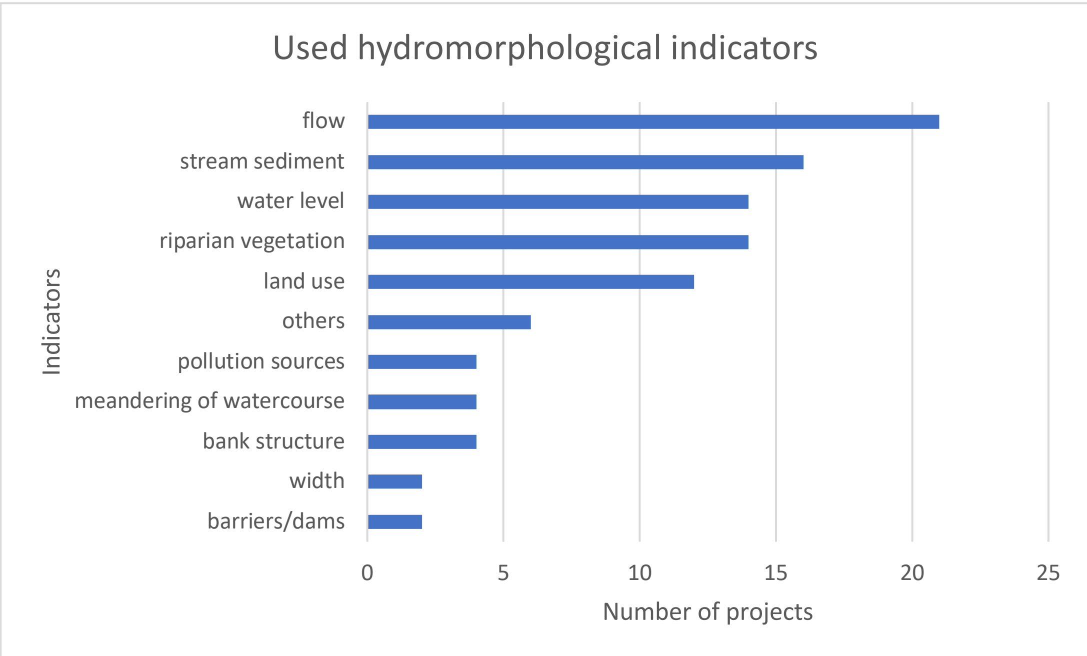

Figure A7 - Used hydromorphological indicators by number of projects. With indicators: flow, stream sediment, water level, riparian vegetation, land use, pollution sources, meandering of watercourse, bank structure, width, barriers and dams and others (more details see Tab. A2).

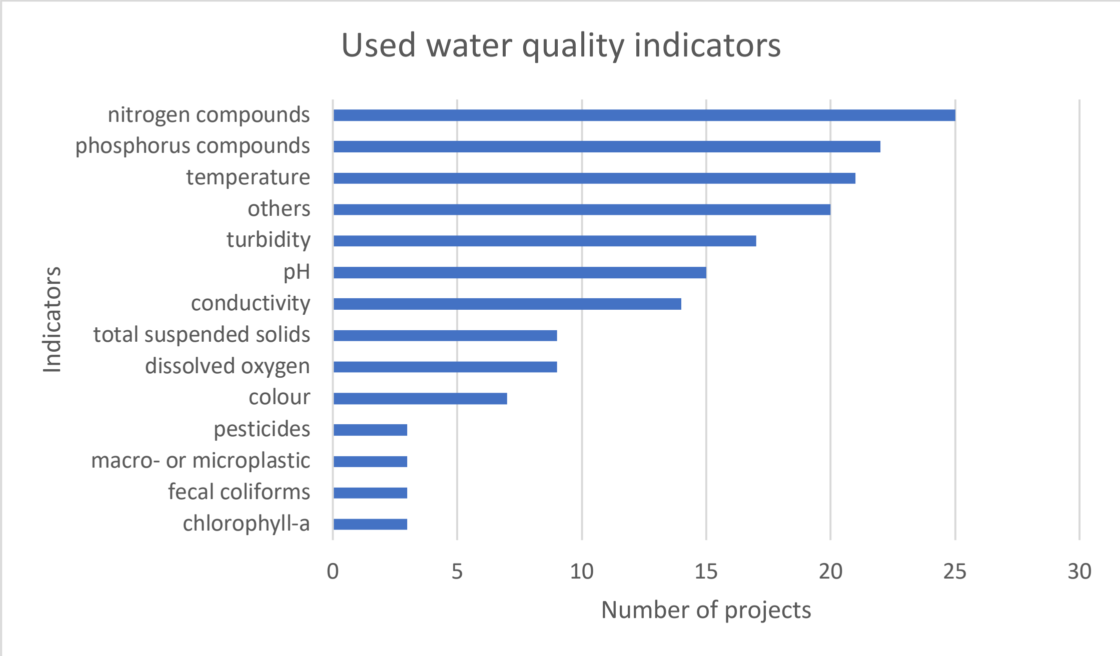

Figure A8 - Used water-quality indicators by number of projects. With indicators: nitrogen compounds, temperature, phosphorus compounds, turbidity, pH, conductivity, total suspended solids, dissolved oxygen, colour, pesticides, macro- and microplastic, fecal coliforms, chlorophyll-a and others (more details see Tab. A3).

Table A9 - Overview of 87 citizen science projects identified in 85 publications. Two papers describe two projects each.

Number	Title	Year	First Author	Journal
1	A unique role for citizen science in ecological restoration: a case study in streams	2018	Edwards	Restoration Ecology
2	MoRPh: a citizen science tool for monitoring and appraising physical habitat changes in rivers	2017	Shuker	Water and Envi-ronment Journal
3	Co-design of a citizen science study: Unlocking the potential of eDNA for volunteer freshwater monitoring	2023	Clarke	Ecological solutions and Evidence
4	Advancing freshwater science with sensor data collected by community scientists	2024	Oviedo-Vargas	Frontiers in Ecology and the Environment
5	Citizen scientists filling knowledge gaps of phosphate pollution dynamics in rural areas	2024	Loiselle	Environmental monitoring and assessment
6	Citizen science data are a reliable complement to quantitative ecological assessments in urban rivers	2020	Krabbenhoft	Ecological indicators
7	Trends and seasonality of river nutrients in agricultural catchments: 18 years of weekly citizen science in France	2018	Abbott	Science of the total environment

8	Assessing water use and quality through youth participatory research in a rural Andean watershed	2009	García	Journal of Environmental man-agement
9	Informing Volunteer Water Quality Monitoring Program Design and Watershed Planning: Case Study of StreamSmart Data Analysis in the Upper White River Basin, Arkansas	2023	Grantz	Journal of Con-temporary Water Research & Education
10	Comparative Analysis of Riverine Plastic Pollution Combining Citizen Science, Remote Sensing and Water Quality Monitoring Techniques	2024	Molnár	Sustainability
11	Citizen science: An alternative way for water monitoring in Hong Kong	2020	Ho	Plos one
12	Engaging a community of interest in water quality protection: Anglers monitoring wadeable streams	2016	Williams	Journal of Soil and Water Conservation
13	Quantification of phytoplankton bloom dynamics by citizen scientists in urban and peri-urban environments	2015	Castilla	Environmental monitoring and assessment
14	Finding clean water habitats in urban landscapes: professional re-searcher vs citizen science	2017	McGoff	Science of the total environ-ment
15	Role of digital technology in freshwater biodiversity monitoring through citizen science during COVID-19 pandemic	2021	Dwivedi	River research and applications
16	Citizen Science for Transition to Sustainability and SDG Monitoring in an Italian River Basin	2024	Sanna	International Journal of E-Planning Re-search
17	Combining citizen science and land use data to identify drivers of eutrophication in the Huangpu River system	2017	Zhang	Science of the total environment
18	Citizen science sampling programs as a technique for monitoring micro-plastic pollution: results, lessons learned and recommendations for working with volunteers for monitoring plastic pollution in freshwater ecosystems	2019	Forrest	Environmental monitoring and assessment

19	Effect of sampling protocol and volunteer bias when sampling for macroinvertebrates	2008	Nerbonne	Journal of the North American Benthological Society
20	Improving Hydrological Models With the Assimilation of Crowdsourced Data	2020	Avellaneda	Water Resources Re-search
21	Anglers' Riverfly Monitoring Initiative (ARMI): A UK-wide citizen science project for water quality assessment	2019	Brooks	Freshwater science
22	Community data - Where does the value lie? Assessing confidence limits of community collected water quality data	2002	Nicholson	Water science and Technology
23	Landscape patterns influence nutrient concentrations in aquatic systems: Citizen science data from Brazil and Mexico	2019	Cunha	Freshwater science
24	A collaborative model for large-scale riparian restoration in the western United States	2015	Oppenheimer	Restoration Ecology
25	The impact of channelization on macroinvertebrate bioindicators in small order Illinois streams: insights from long-term citizen science re-search	2020	Blake	Aquatic Sciences
26	Community-Based Monitoring as the practice of Indigenous communities governance: A case study of Indigenous communities-led water quality monitoring in the Yukon River Basin	2018	Wilson	Journal of Environmental man-agement
27	Insectivorous bat foraging tracks the availability of aquatic flies (Diptera)	2023	Metcalfe	Journal of Wild-life Management
28	Comparative analyses with conventional surveys reveal the potential for an angler app to contribute to recreational fisheries monitoring	2022	Johnston	Canadian Journal of Fisheries and Aquatic Sciences
29	Design and implementation of a cooperative water quality monitoring program in Colorado's Big Thompson Watershed	2003	Greve	Journal of the American Water Resources As-sociation
30	Estimating stream sediment loads to assess management options for a Southern Appalachian mountain	2024	Wilcox	Environmental Earth Sciences

31	Fishery, growth, and mortality of threatened Asian Sunfish, Horabagrus brachysoma (Gu¨nther 1864) in five rivers of Western Ghats hotspot, India	2024	Renjithkumar	Aquatic sciences and engineering
32	In the eye of the beholder: Assessing the water quality of shoreline parks around the Island of Montreal through citizen science	2017	Levesque	Science of the total environment
33	Using cooperative water quality data for a holistic understanding of rivers and streams: A study of the neponset river, Massachusetts	2011	Arrigo	Professional Geographer
34	Estimating aquatic invertebrate diversity in the southern Alps using data from Biodiversity Days	2021	Niedrist	Journal of Lim-nology
35	Population changes for waterways birds, 1980-1981	1982	Taylor	Bird Study
36	Contribution of Citizen Science Data on the Evaluation of regional Biodiversity of Benthic Macroinvertebrate Communities	2025	Lagrotteria	Ecologies
37	Citizen science shows that small agricultural streams in Germany are in a poor ecological status	2024	von Gönner	Science of the total environment
38	A comparison of participatory science seining and electrofishing for sampling fish assemblages in an urban river	2025	Williams	Ecological solutions and Evidence
39	Integrating freshwater science and regional management through volun-teer monitoring partnerships: The Michigan Clean Water Corps	2014	Latimore	Freshwater science
40	Monitoring of Suspended Sediments in a Tropical Forested Landscape With Citizen Science	2021	Njue	Frontiers in water
41	Development of a metric of aquatic invertebrates for volunteers (MAIV): A simple and friendly biotic metric to assess ecological quality of streams	2020	Pinto	Water
42	The contribution of citizen science volunteers to river monitoring and management: International and national perspectives and the example of the MoRPh survey	2019	Gurnell	River research and applications

43	Bridging science and society: Developing a citizen science biomonitoring approach for river ecosystems in Italy	2025	Roccatello	Ecological indicators
44	One-size does not fit all—a networked approach to community-based monitoring in large river basins	2021	Parlee	Sustainability
45	Using partnerships and community science to protect wild and scenic rivers in the Eastern United States	2021	Field-Juma	Sustainability
46	Using partnerships and community science to protect wild and scenic rivers in the Eastern United States	2022	Field-Juma	Sustainability
47	Stakeholder Participation in Freshwater Monitoring and Evaluation Pro-grams: Applying Thresholds of Potential Concern within Environmental Flows	2018	Conallin	Environmental Management
48	Measuring function and structure of urban headwater streams with citi-zen scientists	2019	Kielstra	Ecosphere
49	The "Citizen Sensing Paradigm" to Foster Urban Transitions: Lessons from Civic Environmental Monitoring in Rome	2023	Suman	European Journal of Risk Regulation
50	The "Citizen Sensing Paradigm" to Foster Urban Transitions: Lessons from Civic Environmental Monitoring in Rome	2024	Suman	European Journal of Risk Regulation
51	"Changing behaviour, changing investment, changing operations": Using citizen science to inform the management of an urban river	2019	Cross	Area
52	Assessing the Performance of a Citizen Science Based Water Quality Monitoring Program for Nitrates Using Test Strips Implemented in the Medjerda Hydrosystem in Northern Tunisia	2024	Chaabane	Hydrology
53	Citizen science evidence from the past century shows that Scottish rivers are warming	2019	Pohle	Science of the total environment
54	"The Gems of Water": a co-created scientist-citizen approach for water quality monitoring	2024	Cacciatori	Frontiers in water
55	Student monitoring of the ecological quality of neotropical urban streams	2019	Franca	Ambio

56	The contribution of volunteer-based monitoring data to the assessment of harmful phytoplankton blooms in Brazilian urban streams	2017	Cunha	Science of the total environment
57	World Heritage, Hydropower, and Earth's Largest Freshwater Fish	2023	Lee	Water
58	Fostering Public Participation in Watershed Pollution Governance: A Case Study of Civilian Environmental Supervisors in Guiyang's Dual River Chief System	2024	Huang	Water
59	The Hudson River Eel Project: A community science framework for management and education	2025	Bowser	Fisheries
60	Citizen science pioneers in Kenya – A crowdsourced approach for hydrological monitoring	2018	Weeser	Science of the total environment
61	Citizen Science for Environmental Monitoring in the Eastern Region of Bolivia	2024	Maillard	Sustainability
62	Data fusion of citizen-generated smartphone discharge measurements in Tunisia	2020	Fehri	Journal of Hydrology
63	Pilot application of 'invasive alien species in europe' smartphone app in the danube region	2021	Trichkova	Water
64	Accuracy of long-term volunteer water monitoring data: A multiscale analysis from a statewide citizen science program	2020	Albus	Plos one
65	Quality and timing of crowd-based water level class observations	2020	Etter	Hydrological Processes
66	Trends and Effects of a Recreational Lake Sturgeon Fishery in the St. Clair System	2020	Briggs	North American Journal of Fish-eries Manage-ment
67	Growing pains of crowdsourced stream stage monitoring using mobile phones: The development of crowdhydrology	2019	Lowry	Frontiers in Earth Science
68	How well can people observe the flow state of temporary streams?	2024	Scheller	Frontiers in Envi-ronmental Science

69	Effect of discharge and habitat type on the occurrence and severity of Didymosphenia geminata mats in the Restigouche River, eastern Cana-da	2018	Gillis	Ecohydrology
70	Interdisciplinary approaches to freshwater ecoacoustics	2020	Barclay	Freshwater science
71	Migratory diversity in an Arctic fish supporting subsistence harvest	2020	Hodgson	Biological Con-servation
72	Predicting fish weight using photographic image analysis: a case study of broad whitefish in the lower Mackenzie River watershed	2022	Gutzmann	Arctic Science
73	Detection efficiency of adult Pacific lamprey passage counts at Leaburg Dam and upstream distribution in the McKenzie River (Oregon, USA)	2024	Romer	Ecology of freshwater fish
74	Implementing participatory monitoring in river management: The role of stakeholders' perspectives and incentives	2017	Verbrugge	Journal of Environmental man-agement
75	Towards sponge landscapes through citizen science: participatory monitoring for nature-based solutions in the Ombrone River Basin	2025	Yildiz	Planning practice and re-search
76	Social change innovations, citizen science, miniSASS and the SDGs	2022	Taylor	Water Policy
77	Citizen scientists can help advance the science and management of intermittent rivers and ephemeral streams	2023	Truchy	BioScience
78	Improving water resources management using participatory monitoring in a remote mountainous region of Nepal	2019	Uprety	Journal of Hydrology
79	When predators become prey: Community-based monitoring of caiman and dolphin hunting for the catfish fishery and the broader implications on Amazonian human-natural systems	2018	Pimenta	Biological Conservation
80	Citizen science and land use data provide insight into the invasive riparian plant composition of the Hudson River Valley watershed	2022	Garretson	Invasive Plant Science and Management

81	Anglers as citizen scientists: a case study of resource monitoring in stream salmonids	2024	Tsuboi	Ichthyological research
82	New York State's WAVE Method - Evaluation of a Method for Water Quali-ty Monitoring by Citizen Scientists using Benthic Macroinvertebrates	2023	Onion	Environmental Management
83	Using citizen science to improve the conservation of the European Eel (Anguilla anguilla) in the Thames River Basin District	2018	Pecorelli	Freshwater Science
84	Uncertain monitoring and modeling in a watershed nonpoint pollution program	2017	Wardroppper	Land Use policy
85	The importance of continuous dialogue in community-based wildlife monitoring: Case studies of Dzan and łuk Dagaii in the Gwich'in settlement area	2020	Hovel	Arctic Science
86	IMALIRIJIIT: A Community-Based Environmental Monitoring Program in the George River Watershed, Nunavik,Canada	2018	Gérin-Lajoie	Ecoscience
87	Status of White Sturgeon in the Lower Fraser River, British Colombia	2013	Nelson	Fisheries