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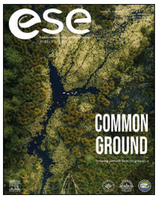

Citizen science powers wetland restoration

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ABSTRACT

Wetlands provide essential ecosystem services, from carbon sequestration and flood mitigation to biodiversity support, yet over 20% have been lost in recent centuries, prompting global restoration efforts backed by policies like the UN Decade on Ecosystem Restoration. Despite rapid expansion of restoration projects, conventional monitoring remains short-term, expert-driven, and often disconnected from site-specific ecological dynamics, limiting adaptive management and long-term success. Citizen science has revolutionized ecological monitoring in other domains by enabling scalable, participatory data collection, but its application to wetland restoration has been largely overlooked. In this Perspective, we assess 120 restoration project sites worldwide and find that citizen science is currently integrated into fewer than 20% of projects even in high-activity regions like Europe, leaving significant social and geographic potential untapped. We find that recent advances in affordable remote sensing, miniaturized sensors, and mobile platforms—supported by rigorous data-validation frameworks—are now overcoming historical constraints regarding data reliability and spatial continuity. These technological shifts, when coupled with emerging institutional recognition, allow citizen-generated data to serve as a scalable, cost-effective infrastructure for monitoring ecological change over meaningful timescales. Systematically integrating public participation into restoration practice is therefore essential for closing critical monitoring gaps and ensuring the long-term sustainability of global wetland ecosystems.

1. Introduction

Globally, more than 20% of wetlands have been lost over the past three centuries, largely due to land-use conversion [1]. Efforts to restore wetlands have accelerated dramatically over the past decade, driven by their vital roles in carbon storage, water regulation, disaster prevention, biodiversity recovery, and cultural ecosystem services such as recreation and aesthetic value [2–5]. Restoration targets are now embedded in global environmental frameworks, from the United Nations Decade on Ecosystem Restoration (2021–2030) [6] to the European Nature Restoration Regulation [7], often backed by substantial public investment. Yet as projects scale across diverse geographies, a central challenge remains unresolved: how do we evaluate restoration success in wetland ecosystems that change slowly, respond nonlinearly, and rarely follow predictable trajectories [8]?

Conventional monitoring approaches offer only a partial answer. Most assessments rely on short-term field activities, static before-and-after comparisons, or intermittent reporting at predefined milestones [9,10]. These snapshots, while useful, often miss early signs of ecological drift or unintended trajectories. In many cases, restoration ends not with a stable or resilient ecosystem, but without a clear sense of whether interventions are working or need adjustment [11]. This shortfall is not simply a technical issue, since tools for tracking hydrology, vegetation, and soil function are available and increasingly affordable [12]. The deeper constraint is institutional: monitoring in wetland restoration remains centralized, expert-led, and short-lived, shaped more by project timelines than by ecological timescales [13].

Addressing this gap requires a fundamental rethinking of how we monitor restored landscapes. Key ecological signs of restoration success, such as the reestablishment of characteristic species assemblages (i.e., structural recovery) [14], the recovery of soil and hydrological functions (i.e., functional recovery) [15], and the

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capacity to withstand disturbances (i.e., ecological resilience) [16], often unfold gradually and unevenly across space and time. They require site-specific, process-sensitive monitoring systems that are sustained over time. Crucially, they also demand broader participation in who observes and thereby informs ecological change. In this context, citizen science (also referred to in some literature as “community science” [17]), the organized participation of members of the public in data collection and environmental monitoring [18], has been proposed as a promising but underused solution.

For decades, policies have increasingly been dedicated to narrowing the gap between science and society, promoting opportunities for innovation and participation in the creation of scientific knowledge and in the sharing of its benefits [19]. One of the most recent frameworks is “Open Science”, which encompasses a range of “open” labels for research practices that aim to improve the public value of science by opening up scientific processes of knowledge production and outcomes to broader audiences, or the “citizen science” field [20].

Despite growing recognition of the value of citizen science, its role in wetland restoration has been limited, as many existing initiatives, including small volunteer- or community-led observations of water quality, biodiversity, or site-level habitat conditions [21,22], remain fragmented and loosely connected to formal monitoring frameworks, often producing isolated scientific or educational insights rather than sustained, decision-relevant information. Moreover, while some large-scale citizen science efforts exist in wetland conservation, such as the global assessments of wetland status and trends conducted through citizen science [23], comparable initiatives in restoration contexts are still rare. This reflects not only practical constraints but also a lack of clear guidance on integrating citizen participation into restoration planning and implementation [24]. Yet recent shifts in technology and governance suggest that citizen science is undergoing a quiet transformation. Advances in mobile platforms, low-cost sensors, and data validation methods have greatly expanded what citizen scientists can observe and report [25–27]. For example, from global biodiversity observations (e.g., eBird, iNaturalist) [28] to soil carbon dynamics (e.g., TeaComposition Initiative) [29] and water quality monitoring efforts (e.g., FreshWater Watch) [30], citizen-generated data systems have proven their capacity to deliver high-quality, spatially dense, and temporally sustained ecological information. At the same time, international frameworks (e.g., the Sustainable Development Goals [31] and the Kunming–Montreal Global Biodiversity Framework [32]) are increasingly cited in calls to recognize citizen-generated data as a valuable complement to official sources.

These changes open new possibilities for applying citizen science to wetland restoration. If citizen science is treated not as an add-on or outreach tool, but as part of the core infrastructure of sustainable restoration processes, it could help close critical gaps in the spatial and temporal continuity of monitoring, which are essential for detecting change and enabling adaptive responses [33,34]. Moreover, from a science and innovation perspective, it will enhance the societal relevance of research practices and align with the democratization of science. Therefore, here we argue that citizen science is not just compatible with wetland restoration but may be essential to its long-term success. In turn, citizen engagement increases scientific literacy, supports lifelong learning, and helps bridge the gap between the scientific community and the public [35].

To make this argument concrete, in this Perspective article, we examine the current extent of citizen science use in wetland restoration, synthesize emerging technological and institutional developments that expand its potential, and outline a pathway for

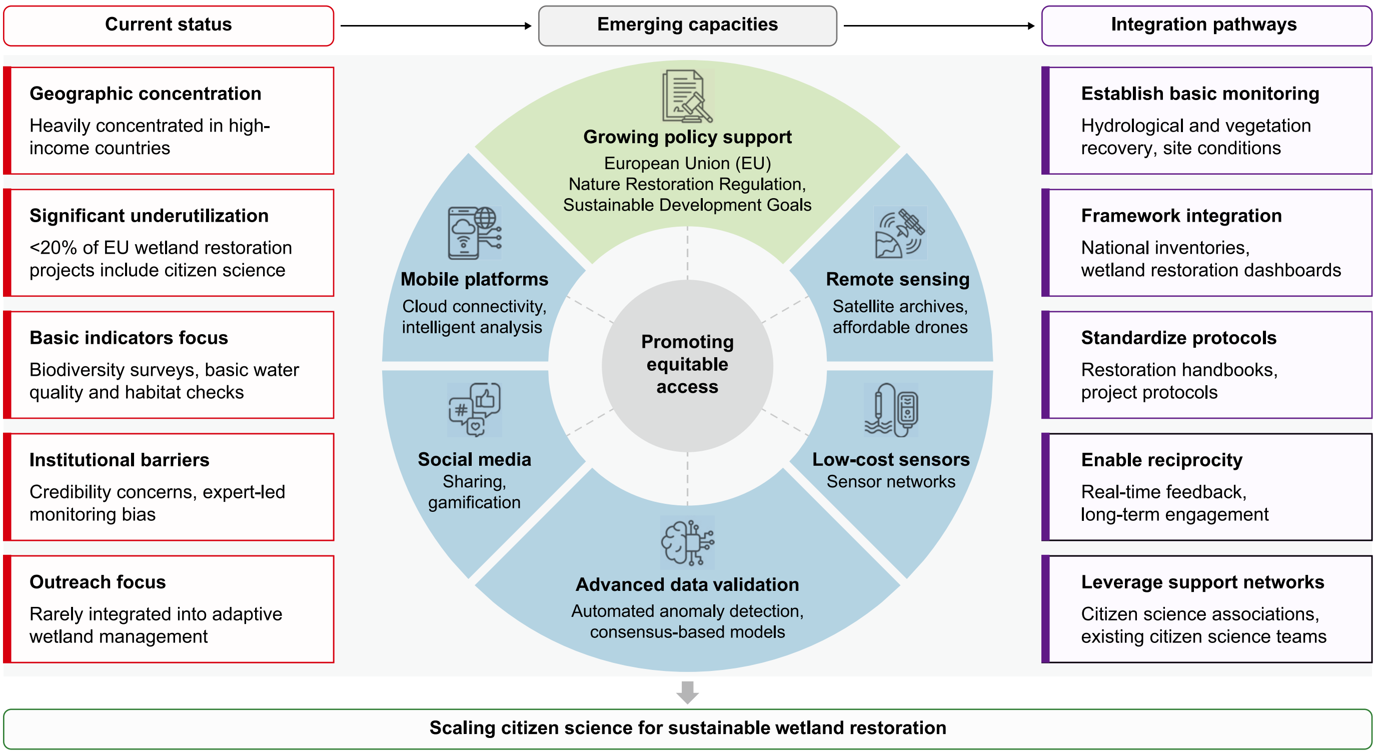

Fig. 1. Roadmap for scaling citizen science in wetland restoration. The figure illustrates the progression from current approaches, where citizen science remains fragmented and marginal, to emerging capacities enabled by technological, social, and institutional advances, and finally toward integration into formal monitoring and adaptive management frameworks. This pathway highlights how citizen science can be scaled into credible and enduring infrastructure, closing spatial, temporal, and institutional gaps that constrain wetland restoration monitoring and long-term success.

integrating citizen-generated data into monitoring and adaptive management (Fig. 1). We aim to clarify how citizen science can move from marginal participation to structural necessity in sustaining long-term wetland restoration.

2. The current situation of citizen science in wetland restoration

Despite growing recognition of citizen science as a tool for ecological and environmental monitoring, its application in wetland restoration remains limited, fragmented, and often informal [24]. Most initiatives are project-specific and short-lived, designed primarily for community engagement or education rather than for generating sustained ecological insights [36,37]. While notable examples exist, particularly in monitoring water quality and species presence [21], they are rare and seldom integrated into decision-making or adaptive management processes.

To better understand how citizen science is currently used in wetland restoration, we searched multiple sources, including European Union project databases, such as the Community Research and Development Information Service (CORDIS) and the Programme for Environment and Climate Action (LIFE), as well as Web of Science, Google Scholar, and Google, to identify restoration projects that incorporated citizen science. Additional details on the search strategy, screening criteria, and screening results are provided in the Supplementary Materials and Supplementary Dataset. Despite extensive searches across multiple sources, the true extent of citizen involvement is likely still underestimated, as many local or community-based initiatives, particularly in low- and middle-income countries, are less visible in official databases or online sources. The patterns presented here should therefore be viewed as a conservative approximation of the actual level of citizen science engagement in wetland restoration.

Geographically, citizen science projects related to wetland restoration are disproportionately concentrated in high-income countries, especially Europe and North America (Fig. 2a–c). This spatial pattern is similar to that observed in other environmental fields, such as soil science [38] and invasive species monitoring [39]. These developed regions typically benefit from strong institutional support, digital infrastructure, and environmental education systems [39,40]. However, even within these regions, the percentage of wetland restoration projects that formally include citizen science appears limited. For instance, in Europe, fewer than 20% of wetland restoration projects explicitly integrate citizen science into their frameworks (Fig. 2d and e), reflecting a significant underutilization of public capacity in formal wetland restoration efforts.

Yet we must acknowledge that in low- and middle-income countries, where wetlands face acute pressures from land conversion and unsustainable use, citizen-generated data are largely absent from formal restoration frameworks [41]. This imbalance reflects deeper asymmetries in funding, institutional capacity, and perceptions of scientific legitimacy, with many restoration programs still reliant on short-term, expert-led monitoring with minimal community engagement [42]. Moreover, in regions such as Latin America, wetland restoration remains relatively uncommon, with efforts more often directed toward conserving remaining wetland ecosystems [43]. In such contexts, both restoration projects and associated citizen science initiatives are understandably scarce.

Where citizen science has been applied to wetland restoration, it has mostly focused on indicators that are both ecologically meaningful and feasible, such as biodiversity surveys, site-level visual assessments, and basic water quality measurements [21,44,45] These efforts already represent a substantial contribution, especially given the inherent challenges of sustaining volunteer participation and maintaining consistent data quality in long-term monitoring. At the same time, key ecological processes that support long-term restoration, such as soil health and greenhouse gas dynamics, have received comparatively less attention in citizen science initiatives, likely because monitoring these parameters usually requires specialized expertise, laboratory analysis, or technically demanding equipment [46].

More fundamentally, the marginal role of citizen science reflects not only institutional tendencies to prioritize expert-led data, but also the practical reality that citizen-generated observations face objective constraints that can affect data comparability [47,48]. These include inconsistent protocols, variation in observer experience or skill, and differences in measurement tools or their calibration [49]. In addition, most wetland restoration programs lack formal mechanisms to validate, integrate, or respond to participatory observations [50,51]. Even when incorporated, it is often framed as a vehicle for outreach, something separate from “real” monitoring, rather than as a component of knowledge production [52]. This reinforces a hierarchy in which only experts are considered qualified to assess ecological outcomes [53]. Overcoming this barrier requires clearer ways to connect citizen observations with formal monitoring, thereby building both credibility and institutional trust.

3. The emerging capacity of citizen science for wetland restoration

Citizen science remains underutilized in wetland restoration, yet its technical and institutional capacity has evolved to speak directly to the challenges of monitoring these ecosystems (Fig. 1). Freely available satellite archives [54–57] and increasingly affordable drones [58–60] make it possible for citizen scientists to detect shifts in vegetation, water distribution, or disturbance events across entire catchments, placing local observations within their wider landscape context. At ground level, the rapid spread of miniaturized sensors has opened access to process-based measurements, such as hydrological conditions [61], water quality [62], soil characteristics [63], biodiversity [64], and even greenhouse gas fluxes [65], that often determine the trajectory of wetland restoration. Many of these devices can even be linked through Internet-of-Things architectures, creating decentralized monitoring networks [65–67], and in some pilot cases, blockchain technologies are being explored to secure data provenance and strengthen trust in citizen-generated data [68].

The ubiquity of mobile platforms amplifies these advances [69]. Smartphones equipped with global positioning systems, cameras, and cloud connectivity have turned into global portals for ecological reporting. Purpose-built applications can translate images into estimates of water quality [70,71], automate species recognition, or channel thousands of geo-referenced observations into shared databases [72,73]. Crucially, by offering intuitive interfaces, offline functionality, and immediate visual feedback, these mobile tools significantly enhance public participation in remote or under-resourced wetland areas [74].

However, sustaining engagement requires more than digital access. Many ecological restoration projects are leveraging social media communities and gamification strategies to reinforce commitment by creating networks of practice, offering recognition, or maintaining interest during slow phases of restoration [75,76]. While such digital tools can broaden participation and help retain volunteers, they should not be viewed as standalone solutions. Over-reliance on technology risks overlooking the deeper, more enduring drivers of participation, such as personal values, connection to nature, desire for social interaction, and a

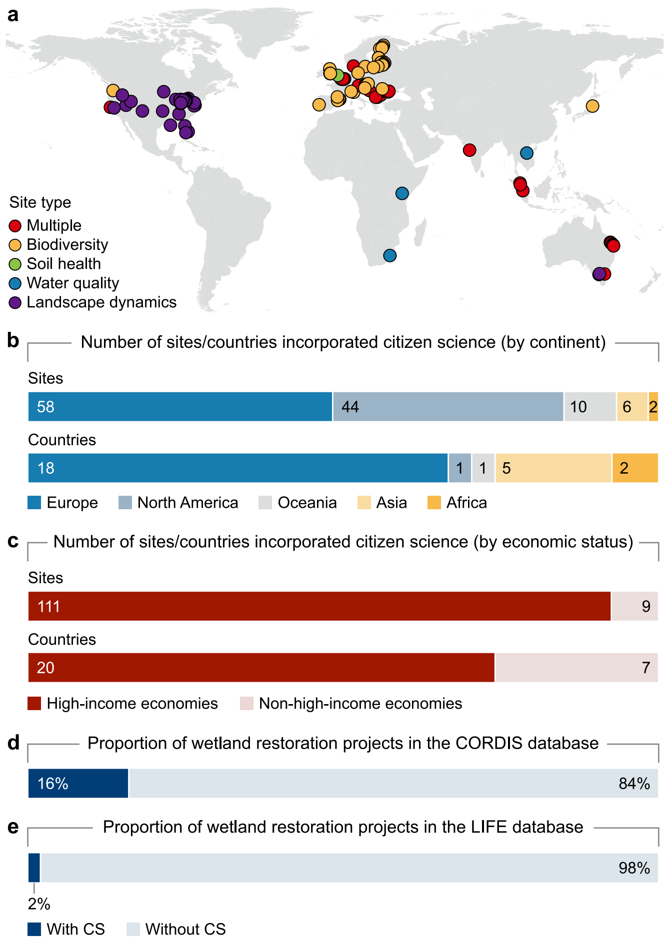

Fig. 2. Geographic and institutional distribution of wetland restoration projects involving citizen science. **a**, Global distribution of wetland restoration sites that incorporated citizen science for ecological monitoring, categorized by thematic focus (e.g., water quality, biodiversity, soil health, landscape dynamics, and multiple indicators). Data was compiled from multiple sources, including European Union project databases, such as the Community Research and Development Information Service (CORDIS) and the Programme for Environment and Climate Action (LIFE), as well as Web of Science, Google Scholar, and Google. $n = 120$. **b**, Number of wetland restoration sites that incorporated citizen science and participating countries grouped by continent. Data was compiled from CORDIS, LIFE, Web of Science, Google Scholar, and Google. **c**, Number of wetland restoration sites that incorporated citizen science and participating countries grouped by economic status (high-income economies versus non-high-income economies, classified by the World Bank's income categories in fiscal year 2024). Data was compiled from CORDIS, LIFE, Web of Science, Google Scholar, and Google. **d**, Proportion of wetland restoration projects in the CORDIS database that explicitly integrate citizen science (CS). **e**, Proportion of wetland restoration projects in the LIFE database that explicitly integrate CS. Detailed data search methods are in the Supplementary Materials. Detailed information on wetland restoration projects/sites that incorporate citizen science is provided in the Supplementary Dataset.

desire to contribute to science and policy. Early identification of citizen scientists' motivations and continuous assessment of how these motivations evolve are essential for fostering successful and sustainable citizen science monitoring programs [77,78].

Even where participation is strong, skepticism about data quality and institutional legitimacy has long constrained the integration of citizen science into restoration. Such concerns are not trivial: restoration decisions often involve substantial investment and long time horizons, and managers have been reluctant to rely on information perceived as inconsistent or unverifiable. Experience from large-scale ecological citizen science programs shows that addressing these concerns requires treating data quality as a full lifecycle process, beginning with task design and extending through verification and documentation [49]. Iterative protocol refinement, targeted volunteer training, clear task definitions, replication across observers, and standardized data-entry interfaces reduce errors at the point of collection. Meanwhile, expert review, community consensus, and automated anomaly detection can be combined into hierarchical workflows that triage most records algorithmically and escalate only uncertain entries to expert validators [79]. To make such verification systems interoperable with professional wetland monitoring, they must be paired with standardized procedures that document how each record was produced [80]. Harmonized protocols, basic metadata standards (e.g., who collected what, where, when, and with which method or device), calibration of low-cost sensors against reference instruments, and transparent quality assurance and quality control documentation allow citizen-generated observations to be assigned clear quality flags or scores [49,80]. This enables them to be jointly analyzed, filtered, or weighted with professional datasets, based on documented reliability rather than their origin [81]. In wetland restoration, such standardization provides a realistic pathway for citizen-generated data to enter the same analytical pipelines as agency data while preserving information on uncertainty and verification history.

Furthermore, these technical and social transformations are increasingly reinforced by institutional change. For example, in Europe, citizen-generated data have long underpinned implementation of the Birds Directive [82], and the recent European Nature Restoration Regulation encourages Member States to promote citizen science in ecological monitoring and to allocate adequate resources to support such activities [7]. In the United States, the proportion of environmental impact statements that referenced or incorporated citizen science increased from 3% in 2012 to 40% in 2022 [83].

These developments are particularly important in regions where expert-led assessments are infrequent or under-resourced. With appropriate data validation and sufficient guidance from scientists to align data collection with specific requirements for the restoration process, and with interoperable infrastructure and emerging policy support, citizen science is increasingly positioned to provide credible, decision-relevant data for wetland restoration at scale. Realizing this potential, however, also requires attention to equity, for example, ensuring that access to digital and participatory tools is not confined to well-resourced contexts but extends to regions where wetlands face the most acute pressures.

4. Integrating citizen science into wetland restoration

Although recent advances in sensing technologies, mobile platforms, and participatory data systems have greatly expanded what citizen scientists can observe and report, these capacities remain largely disconnected from the institutional structures of wetland restoration. Citizen science often operates in parallel to expert-led assessments, with limited influence on how restoration progress is assessed or how interventions are adjusted, leaving its potential underrealized. The challenge now lies in moving from fragmented initiatives toward integrated monitoring frameworks (Fig. 1) in which citizen-generated data are systematically validated, embedded in reporting structures, and linked to adaptive management.

Advancing this integration will require both bottom–up and top–down pathways. Bottom–up participation can generate fine-scale, context-rich observations that would otherwise be difficult or expensive to obtain, particularly when supported by global platforms such as iNaturalist that enable locally driven monitoring while contributing to global-scale datasets [84,85]. At the same time, top–down recognition from policymakers, funding bodies, and restoration agencies is essential to ensure that citizen-generated data are meaningfully incorporated into formal monitoring frameworks and adaptive management. Harnessing both approaches allows wetland restoration to benefit from local ecological knowledge while strengthening large-scale assessments.

To translate these principles into practice, a practical starting point is to encourage restoration projects to establish basic, ongoing monitoring activities where citizen participation is feasible. Even relatively straightforward contributions, such as tracking water levels, taking repeat photographs of vegetation, or documenting local biodiversity, can help generate locally relevant observations that complement expert assessments. Where such practices exist, the next step is to explore how citizen-generated data might be gradually incorporated into existing monitoring frameworks and reporting structures, including national wetland inventories or restoration dashboards. Achieving this requires engagement not only from practitioners but also from the agencies and policymakers responsible for designing these systems, since top–down support is essential for ensuring that citizen contributions are formally recognized. This can help improve spatial coverage and temporal continuity, while also giving greater visibility and legitimacy to community contributions.

When sufficient experience has been gained, guidance can be strengthened at the project design level. Most current restoration handbooks and guidelines either overlook citizen science or treat it as an optional add-on [24]. This marginalization leaves practitioners and citizen scientists without concrete guidance on where, when, and how public contributions can support long-term monitoring. To unlock this potential, restoration frameworks can provide clear protocols for citizen engagement across relevant ecological indicators and specify how these data can be integrated into adaptive management. Doing so transforms citizen science from symbolic outreach into a structured, scalable mechanism for sustaining ecological observation beyond the limits of expert-led monitoring.

Sustained engagement depends not only on participation but on reciprocity. Many citizen science initiatives are deeply place-based, driven by long-standing commitments to the care and stewardship of local landscapes [86]. Recognizing and supporting these place-based motivations can help sustain participation over long restoration timelines. Given the time and effort required for wetland monitoring, providing appropriate material and symbolic rewards or compensation can further encourage long-term, continuous participation [87]. Volunteers are also more likely to remain involved when they understand how their contributions are used, what decisions those data inform, and where additional information is still needed. Digital platforms can help facilitate this exchange, offering real-time feedback, data visualization, and opportunities for co-interpretation of ecological trends. At the same time, reliance on cloud platforms and social media raises concerns over privacy, ownership, and consent, underscoring the need for clear governance to safeguard contributors and sustain trust in citizen-generated data. Monitoring systems must also account for cultural differences and diverse participant needs, adapting project design to meaningfully activate training and support volunteers beyond digital incentives. A human-centered approach that complements technological tools with the acknowledgment of intrinsic and extrinsic motivations of participants is key to long-term engagement [78,88,89].

Importantly, restoration teams do not need to navigate these integration challenges alone. A growing number of international and national citizen science networks, such as the European Citizen Science Association, the Australian Citizen Science Association, and the Association for Advancing Participatory Sciences in the United States, now offer platforms for theoretical guidance, methodological support, and peer support [90], which can help wetland projects incorporate citizen science more effectively and credibly. In parallel, many countries also host active regional or local citizen science associations that provide more context-specific guidance aligned with domestic legislation, conservation priorities, and existing wetland management frameworks [90]. Beyond professional networks, collaboration with existing citizen science teams (such as those in universities and research institutions) can provide hands-on support during wetland restoration monitoring, which seems particularly applicable to many university-led restoration projects.

Step by step, integrating citizen science into wetland restoration can help strengthen ecological monitoring by filling gaps in formal monitoring programs. It can provide broader spatial coverage, more frequent observations, and local context. This additional information improves the basis for adaptive management, especially in resource-limited settings or under rapidly changing conditions. In this way, citizen science offers a practical, scalable approach to extend monitoring capacity and support sustainable wetland restoration.

CRediT authorship contribution statement

Shihao Cui: Writing - Review & Editing, Writing - Original Draft, Visualization, Methodology, Investigation, Formal Analysis, Data Curation, Conceptualization. **Haonan Guo:** Writing - Review & Editing, Visualization, Investigation, Data Curation. **Lorenzo Pugliese:** Writing - Review & Editing, Supervision, Methodology. **Gitte Kragh:** Writing - Review & Editing, Methodology. **Sonia Mena:** Writing - Review & Editing, Methodology. **Shubiao Wu:** Writing - Review & Editing, Supervision, Project Administration, Methodology, Funding Acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ese.2026.100656.

References

[1] E. Fluet-Chouinard, B.D. Stocker, Z. Zhang, A. Malhotra, J.R. Melton, B. Poulter, J.O. Kaplan, K.K. Goldewijk, S. Siebert, T. Minayeva, Extensive global wetland loss over the past three centuries, Nature 614 (7947) (2023) 281–286.

[2] J. Zou, A.D. Ziegler, D. Chen, G. McNicol, P. Ciais, X. Jiang, C. Zheng, J. Wu, J. Wu, Z. Lin, Rewetting global wetlands effectively reduces major greenhouse gas emissions, Nat. Geosci. 15 (8) (2022) 627–632.

[3] C. Fu, A. Steckbauer, H. Mann, C.M. Duarte, Achieving the Kunming–Montreal global biodiversity targets for blue carbon ecosystems, Nat. Rev. Earth Environ. 5 (7) (2024) 538–552.

[4] K.A. Wood, L.L. Jupe, F.C. Aguiar, A.M. Collins, S.J. Davidson, W. Freeman, L. Kirkpatrick, T. Lobato-de Magalhães, E. McKinley, A. Nuno, A global systematic review of the cultural ecosystem services provided by wetlands, Ecosyst. Serv. 70 (2024) 101673.

[5] P.D. McElwee, K.E. Allen, R.K. Gould, M. Hsu, J. He, The Routledge Handbook of Cultural Ecosystem Services, Taylor & Francis, 2025.

[6] United Nations, United Nations Decade on Ecosystem Restoration (2021–2030): Resolution. UN. General Assembly, 73rd sess. : 2018-2019, 2019.

[7] European Commission: Directorate-General for Environment, Nature Restoration Law – for People, Climate, and Planet, Publications Office of the European Union, 2022.

[8] A.L. Mayer, M. Rietkerk, The dynamic regime concept for ecosystem management and restoration, Bioscience 54 (11) (2004) 1013–1020.

[9] M.C. Ruiz-Jaen, T. Mitchell Aide, Restoration success: how is it being measured? Restor. Ecol. 13 (3) (2005) 569–577.

[10] J.E.A. Huddart, M.S.A. Thompson, G. Woodward, S.J. Brooks, Citizen science: from detecting pollution to evaluating ecological restoration, Wiley Interdiscip. Rev.: Water. 3 (3) (2016) 287–300.

[11] S. Galatowitsch, J. Bohnen, Long-term recovery of a restored palustrine wetland: the role of monitoring and adaptive management, Wetlands 41 (6) (2021) 80.

[12] L.K. Sharma, R. Naik, Present Technologies for Wetland Studies, Conservation of Saline Wetland Ecosystems: an Initiative Towards UN Decade of Ecological Restoration, Springer, 2024, pp. 115–173.

[13] M. Adam, D.J. Cooper, R. Jaunatre, J.C. Clément, S. Gaucherand, Wetland restoration: can short-term success criteria predict long-term outcomes? Restor. Ecol. 32 (7) (2024) e14231.

[14] J. Kreyling, F. Tanneberger, F. Jansen, S. van der Linden, C. Aggenbach, V. Blüml, J. Couwenberg, W.J. Emsens, H. Joosten, A. Klimkowska, Rewetting does not return drained fen peatlands to their old selves, Nat. Commun. 12 (1) (2021) 1–8.

[15] R. Andersen, C. Wells, M. Macrae, J. Price, Nutrient mineralisation and microbial functional diversity in a restored bog approach natural conditions 10 years post restoration, Soil Biol. Biochem. 64 (2013) 37–47.

[16] J. Loisel, A. Gallego-Sala, Ecological resilience of restored peatlands to climate change, Commun. Earth Environ. 3 (1) (2022) 208.

[17] D.E. Lin Hunter, G.J. Newman, M.M. Balgopal, What's in a name? The paradox of citizen science and community science, Front. Ecol. Environ. 21 (5) (2023) 244–250.

[18] D. Fraisl, G. Hager, B. Bedessem, M. Gold, P.-Y. Hsing, F. Danielsen, C.B. Hitchcock, J.M. Hulbert, J. Piera, H. Spiers, Citizen science in environmental and ecological sciences, Nat. Rev. Methods Primers 2 (1) (2022) 64.

[19] Unesco, Open Science Outlook 1: Status and Trends Around the World, UNESCO, Paris, France, 2023.

[20] U. Wehn, R. Ajates, C. Mandeville, L. Somerwill, G. Kragh, M. Haklay, Opening science to society: how to progress societal engagement into (open) science policies, R. Soc. Open Sci. 11 (5) (2024) 231309.

[21] K.D. Yardi, E. Bharucha, S. Girade, Post-restoration monitoring of water quality and avifaunal diversity of Pashan Lake, Pune, India using a citizen science approach, Freshw. Sci. 38 (2) (2019) 332–341.

[22] D. Terzano, F. Attorre, F. Parish, P. Moss, F. Bresciani, R. Cooke, P. Dargusch, Community-led peatland restoration in Southeast Asia: 5Rs approach, Restor. Ecol. 30 (8) (2022) e13642.

[23] R.J. McInnes, N.C. Davidson, C.P. Rostron, M. Simpson, C.M. Finlayson, A citizen science state of the world's wetlands survey, Wetlands 40 (5) (2020) 1577–1593.

[24] M. Santaoja, T. Squires, A. Klimkowska, S. Mc Guinness, G. Granath, T. Törmänen, I. Biedroń, A. Terrisse, Best practices in European wetland restoration: a review of manuals and guidelines, Wetl. Ecol. Manag. 33 (4) (2025) 54.

[25] G. Newman, A. Wiggins, A. Crall, E. Graham, S. Newman, K. Crowston, The future of citizen science: emerging technologies and shifting paradigms, Front. Ecol. Environ. 10 (6) (2012) 298–304.

[26] J.K. Sheard, T. Adriaens, D.E. Bowler, A. Büermann, C.T. Callaghan, E.C.M. Camprasse, S. Chowdhury, T. Engel, E.A. Finch, J. Von Gönner, Emerging technologies in citizen science and potential for insect monitoring, Philos. Trans. R. Soc. B 379 (1904) (2024) 20230106.

[27] B. Baker, Frontiers of citizen science: explosive growth in low-cost technologies engage the public in research, Bioscience 66 (11) (2016) 921–927.

[28] S. Stoudt, B.R. Goldstein, P. de Valpine, Identifying engaging bird species and traits with community science observations, Proc. Natl. Acad. Sci. 119 (16) (2022) e2110156119.

[29] J.M. Sarneel, M.M. Hefting, T. Sandén, J. van den Hoogen, D. Routh, B.S. Adhikari, J.M. Alatalo, A. Aleksanyan, I.H.J. Althuizen, M.H.S.A. Alsafran, Reading tea leaves worldwide: decoupled drivers of initial litter decomposition mass-loss rate and stabilization, Ecol. Lett. 27 (5) (2024).

[30] I. Bishop, A. Boldrini, W. Clymans, C. Hall, H. Moorhouse, S. Parkinson, K. Scott-Somme, I. Thornhill, S. Loiselle, FreshWater watch: investigating the health of freshwater ecosystems, from the bottom up, Citiz. Sci. Theory Pract. 10 (1) (2025).

[31] S. Fritz, L. See, T. Carlson, M. Haklay, J.L. Oliver, D. Fraisl, R. Mondardini, M. Brocklehurst, L.A. Shanley, S. Schade, Citizen science and the United Nations sustainable development goals, Nat. Sustain. 2 (10) (2019) 922–930.

[32] F. Danielsen, N. Ali, H.T. Andrianandrasana, A. Baquero, U. Basilius, P. de Araujo Lima Constantino, K. Despot-Belmonte, P.O. Frederiksen, M. Isaac, P. Jakobsen, Involving citizens in monitoring the Kunming–Montreal global biodiversity framework, Nat. Sustain. 7 (12) (2024) 1730–1739.

[33] J. Hadj-Hammou, S. Loiselle, D. Ophof, I. Thornhill, Getting the full picture: assessing the complementarity of citizen science and agency monitoring data, PLoS One 12 (12) (2017) e0188507.

[34] W.M. Hochachka, D. Fink, R.A. Hutchinson, D. Sheldon, W.-K. Wong, S. Kelling, Data-intensive science applied to broad-scale citizen science, Trends Ecol. Evol. 27 (2) (2012) 130–137.

[35] E.S. Urválková, S. Janoušková, Citizen science–bridging the gap between scientists and amateurs, Chem. Teach. Int. 1 (2) (2019) 20180032.

[36] S. Den Haan, The human side of ecosystem restoration: identifying community engagement strategies that support the long-term success of European wetland restoration projects, Master's thesis, International Institute for Industrial Environmental Economics (IIIEE), Lund University, Sweden (2021).

[37] E. McKinley, M.I. Garcia Rojas, M.M. Palacios, C.G. Nichols, A. Bhattacharjee, P.I. Macreadie, Immersive citizen science experiences and their role in changing perceptions of coastal wetlands, People Nat. 6 (6) (2024) 2261–2282.

[38] V. Pino, A. McBratney, E. O'Brien, K. Singh, L. Pozza, Citizen science & soil connectivity: where are we? Soil Secur. 9 (2022) 100073.

[39] M.J.O. Pocock, T. Adriaens, S. Bertolino, R. Eschen, F. Essl, P.E. Hulme, J.M. Jeschke, H.E. Roy, H. Teixeira, M. De Groot, Citizen science is a vital partnership for invasive alien species management and research, iScience 27 (1) (2024).

[40] M.E. Haklay, Citizen Science and Policy: a European Perspective, Woodrow Wilson International Center for Scholars, Washington, DC, 2015.

[41] F. Requier, G.K.S. Andersson, F.J. Oddi, L.A. Garibaldi, Citizen science in developing countries: how to improve volunteer participation, Front. Ecol. Environ. 18 (2) (2020) 101–108.

[42] M. Pasgaard, C.A. Breed, M. Heins, L. Knudsen, P. Brom, A. Schmidt, K. Engemann, Citizen science beyond science: a collaborative approach for transformative sustainable development, Citiz. Sci. Theory Pract. 8 (1) (2023) 41.

[43] F. Wittmann, E. Householder, A. de Oliveira Wittmann, A. Lopes, W.J. Junk, M.T.F. Piedade, Implementation of the Ramsar Convention on South American wetlands: an update, Res. Rep. Biodivers. Stud. (2015) 47–58.

[44] H. Kobori, Current trends in conservation education in Japan, Biol. Conserv. 142 (9) (2009) 1950–1957.

[45] M. Ardon-Sayao, CAREER: trajectories of ecosystem recovery in coastal wetlands under a changing climate: connecting the dots with student research, citizen science, and classroom data analyses. NSF Award Number 1713502, Dir. Biol. Sci. 17 (1713502) (2016) 13502.

[46] J.S. Head, M.E. Crockatt, Z. Didarali, M.-J. Woodward, B.A. Emmett, The role of citizen science in meeting SDG targets around soil health, Sustainability 12 (24) (2020) 10254.

[47] R. Lukyanenko, J. Parsons, Y.F. Wiersma, Emerging problems of data quality in citizen science, Conserv. Biol. 30 (3) (2016) 447–449.

[48] A. Johnston, E. Matechou, E.B. Dennis, Outstanding challenges and future directions for biodiversity monitoring using citizen science data, Methods Ecol. Evol. 14 (1) (2023) 103–116.

[49] M. Kosmala, A. Wiggins, A. Swanson, B. Simmons, Assessing data quality in citizen science, Front. Ecol. Environ. 14 (10) (2016) 551–560.

[50] Z. Lobat, A. Saeed, H.R. Jafari, B.K. Masoud, Sustainable wetland management through bridging the communication gap between conservation projects and local communities, Environ. Dev. Sustain. 23 (7) (2021) 11098–11119.

[51] A.-M. Pop, G.-G. Hognogi, R.-H. Bătinaş, Who's voice counts? Managing conservation and sustainable valorisation of peatlands, Environ. Sci. Eur. 37 (1) (2025) 1–19.

[52] C.G. Druschke, K.C. Hychka, Manager perspectives on communication and public engagement in ecological restoration project success, Ecol. Soc. 20 (1) (2015).

[53] M.J. Feio, A.R. Calapez, C.L. Elias, R.M.V. Cortes, M.A.S. Graça, P. Pinto, S.F.P. Almeida, The paradox of expert judgment in rivers ecological monitoring, J. Environ. Manag. 184 (2016) 609–616.

[54] Q. Demarquet, S. Rapinel, S. Dufour, L. Hubert-Moy, Long-term wetland monitoring using the landsat archive: a review, Remote Sens. 15 (3) (2023) 820.

[55] J. Muro, M. Canty, K. Conradsen, C. Hüttich, A.A. Nielsen, H. Skriver, F. Remy, A. Strauch, F. Thonfeld, G. Menz, Short-term change detection in wetlands using Sentinel-1 time series, Remote Sens. 8 (10) (2016) 795.

[56] L. See, S. Fritz, C. Perger, C. Schill, I. McCallum, D. Schepaschenko, M. Duerauer, T. Sturn, M. Karner, F. Kraxner, Harnessing the power of volunteers, the internet and Google Earth to collect and validate global spatial information using Geo-Wiki, Technol. Forecast. Soc. Change 98 (2015) 324–335.

[57] S. Fritz, L. See, C. Perger, I. McCallum, C. Schill, D. Schepaschenko, M. Duerauer, M. Karner, C. Dresel, J.-C. Laso-Bayas, A global dataset of crowdsourced land cover and land use reference data, Sci. Data 4 (1) (2017) 1–8.

[58] J.M. Robinson, P.A. Harrison, S. Mavoa, M.F. Breed, Existing and emerging uses of drones in restoration ecology, Methods Ecol. Evol. 13 (9) (2022) 1899–1911.

[59] S.A. Wood, P.W. Robinson, D.P. Costa, R.S. Beltran, Accuracy and precision of citizen scientist animal counts from drone imagery, PLoS One 16 (2) (2021) e0244040.

[60] A. Varela-Jaramillo, C. Winkelmann, A. Mármol-Guijarro, J.M. Guayasamin, G. Rivas-Torres, S. Steinfartz, A. MacLeod, Citizen scientists reliably count endangered Galápagos marine iguanas from drone images, Sci. Rep. 15 (1) (2025) 26884.

[61] J.D. Paul, W. Buytaert, Citizen science and low-cost sensors for integrated

water resources management. Advances in Chemical Pollution, Environmental Management and Protection, Elsevier, 2018, pp. 1–33.

[62] S.B. Ramírez, I. van Meerveld, J. Seibert, Citizen science approaches for water quality measurements, Sci. Total Environ. (2023) 165436.

[63] C. Corbari, N. Paciolla, I. Ben Charfi, D. Skokovic, J.A. Sobrino, M. Woods, Citizen science supporting agricultural monitoring with hundreds of low-cost sensors in comparison to remote sensing data, Eur. J. Remote Sens. 55 (1) (2022) 388–408.

[64] A.P. Hill, P. Prince, E. Piña Covarrubias, C.P. Doncaster, J.L. Snaddon, A. Rogers AudioMoth, Evaluation of a smart open acoustic device for monitoring biodiversity and the environment, Methods Ecol. Evol. 9 (5) (2018) 1199–1211.

[65] N. Okafor, R. Ingle, U. Matthew, M. Saunders, D. Delaney, Assessing and improving IoT sensor data quality in environmental monitoring networks: a focus on peatlands, IEEE Internet Things J. 11 (24) (2024) 40727–40742.

[66] Y. Jia, LoRa-based WSNs construction and low-power data collection strategy for wetland environmental monitoring, Wirel. Pers. Commun. 114 (2) (2020) 1533–1555.

[67] J. Hao, R. Sharma, M.B. Fleming, I.K. Kim, D.R. Mishra, S.S. Kim, L.A. Sutter, L. Ramaswamy, Toward low-cost and sustainable IoT systems for soil monitoring in coastal wetlands, in: 2023 IEEE 9th International Conference on Collaboration and Internet Computing (CIC), 2023, pp. 52–61.

[68] S.S. Warrier, R.M. Samuel, H. Mukundan, N.B.S. Shibu, A.R. Devidas, Leveraging IoT and blockchain technologies for Wetland monitoring and community engagement, in: 2024 15th International Conference on Computing Communication and Networking Technologies (ICCCNT), 2024, pp. 1–7.

[69] G.-G. Hognogi, M. Meltzer, F. Alexandrescu, L. Ștefănescu, The role of citizen science mobile apps in facilitating a contemporary digital agora, Humanit. Soc. Sci. Commun. 10 (1) (2023) 1–16.

[70] T.J. Malthus, R. Ohmsen, H.J.v. d. Woerd, An evaluation of citizen science smartphone apps for inland water quality assessment, Remote Sens. 12 (10) (2020) 1578.

[71] S. Zheng, H. Li, T. Fang, G. Bo, D. Yuan, J. Ma, Towards citizen science. On-site detection of nitrite and ammonium using a smartphone and social media software, Sci. Total Environ. 815 (2022) 152613.

[72] N. Jakuschona, T. Niers, J. Stenkamp, T. Bartoschek, S. Schade, A.C. Cardoso, Evaluating Image-based Species Recognition Models Suitable for Citizen Science Application to Support European Invasive Alien Species Policy, Publications Office of the European Union, Luxembourg, 2022.

[73] T. Lefort, A. Affouard, B. Charlier, J.C. Lombardo, M. Chouet, H. Goëau, J. Salmon, P. Bonnet, A. Joly, Cooperative learning of Pl@ ntNet's Artificial Intelligence algorithm: how does it work and how can we improve it? Methods Ecol. Evol. (2025).

[74] N.B. Pattinson, J. Taylor, C.W.S. Dickens, P.M. Graham, Digital Innovation in Citizen Science to Enhance Water Quality Monitoring in Developing Countries, 210, IWMI, 2023.

[75] S.S. Oliveira, B. Barros, J.L. Pereira, P.T. Santos, R. Pereira, Social media use by citizen science projects: characterization and recommendations, Front. Environ. Sci. 9 (2021) 715319.

[76] K.V. Kreitmair, D.C. Magnus, Citizen science and gamification, Hastings Cent. Rep. 49 (2) (2019) 40–46.

[77] O. Nov, O. Arazy, D. Anderson, Scientists@ home: what drives the quantity and quality of online citizen science participation? PLoS One 9 (4) (2014) e90375.

[78] A. Richter, O. Comay, C.S. Svenningsen, J.C. Larsen, S. Hecker, A.P. Tøttrup, G. Pe'er, R.R. Dunn, A. Bonn, M. Marselle, Motivation and support services in citizen science insect monitoring: a cross-country study, Biol. Conserv. 263 (2021) 109325.

[79] E. Baker, J.P. Drury, J. Judge, D.B. Roy, G.C. Smith, P.A. Stephens, The verification of ecological citizen science data: current approaches and future possibilities, Citiz. Sci. Theory Pract. 6 (1) (2021).

[80] R.R. Downs, H.K. Ramapriyan, G. Peng, Y. Wei, Perspectives on citizen science data quality, Front. Clim. 3 (2021) 615032.

[81] K. Vohland, A. Land-Zandstra, L. Ceccaroni, R. Lemmens, J. Perelló, M. Ponti, R. Samson, K. Wagenknecht, The Science of Citizen Science, Springer Nature, 2021.

[82] V. Pellissier, R. Schmucki, G. Pe'er, A. Aunins, T.M. Brereton, L. Brotons, J. Carnicer, T. Chodkiewicz, P. Chylarecki, J.C. Del Moral, Effects of Natura 2000 on nontarget bird and butterfly species based on citizen science data, Conserv. Biol. 34 (3) (2020) 666–676.

[83] C.T. Callaghan, C. Winnebald, B. Smith, B.M. Mason, L. López-Hoffman, Citizen science as a valuable tool for environmental review, Front. Ecol. Environ. 23 (1) (2025) e2808.

[84] B.M. Mason, T. Mesaglio, J. Barratt Heitmann, M. Chandler, S. Chowdhury, S.B.Z. Gorta, F. Grattarola, Q. Groom, C. Hitchcock, L. Hoskins, iNaturalist accelerates biodiversity research, Bioscience 75 (11) (2025) 953–965.

[85] S. Baasanmunkh, B. Oyuntsetseg, Z. Tsegmed, A. Undruul, D. Munkhtulga, M. Urgamal, N. Nyambayar, C. Javzandolgor, C. Bayarmaa, D. Narangarvuu, iNaturalist projects represent a valuable resource for aggregating plant observations and engaging society: a case study of the Flora of Mongolia project, Plants, People, Planet 8 (1) (2025) 26–37.

[86] G. Newman, M. Chandler, M. Clyde, B. McGreavy, M. Haklay, H. Ballard, S. Gray, R. Scarpino, R. Hauptfeld, D. Mellor, Leveraging the power of place in citizen science for effective conservation decision making, Biol. Conserv. 208 (2017) 55–64.

[87] M. Lotfian, J. Ingensand, M.A. Brovelli, A framework for classifying participant motivation that considers the typology of citizen science projects, ISPRS Int. J. GeoInf. 9 (12) (2020) 704.

[88] S. Liñán, X. Salvador, A. Alvarez, A. Comaposada, L. Sanchez, N. Aparicio, I. Rodero, J. Piera, A new theoretical engagement framework for citizen science projects: using a multi-temporal approach to address long-term public engagement challenges, Environ. Res. Lett. 17 (10) (2022) 105006.

[89] U. Koedel, P. Dietrich, T. Herrmann, C. Liang, O. Ritter, J. Roettenbacher, F.M. Schuetze, S.V. Schuetze, J.C. Thoboell, C. Schuetze, Enhancing citizen science impact in environmental monitoring: targeted engagement strategies with stakeholder groups, Front. Environ. Sci. 12 (2024) 1375675.

[90] M. Storksdieck, J.L. Shirk, J.L. Cappadonna, M. Domroese, C. Göbel, M. Haklay, A.J. Miller-Rushing, P. Roetman, C. Sbrocchi, K. Vohland, Associations for citizen science: regional knowledge, global collaboration, Citiz. Sci. Theory Pract. 1 (2) (2016), 10-10.