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Advancing data integration in marine citizen science: insights from a collaborative workshop

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The ocean remains critically under-observed, particularly in coastal zones where traditional monitoring is limited by cost, logistical constraints, and competing regulatory priorities. Marine citizen science offers an emerging and powerful complementary approach to addressing these gaps; however, data management challenges currently limit its full integration into scientific and policy data infrastructures. The inaugural workshop of the Marine Citizen Science Data Network (MCS DN), held in February 2026 in Ostend, Belgium, brought together approximately 200 participants from over 30 countries. Attendees included representatives from marine citizen science initiatives, developers of low-cost monitoring devices, data managers, and researchers and data users. Together they identified challenges, opportunities and co-designed recommendations to improve marine citizen science data flows. Workshop discussions highlighted interconnected barriers and enabling factors affecting FAIR (Findable, Accessible, Interoperable, and Reusable) marine citizen science data. These included fragmented data flows, weak connections between communities, limited participant engagement and feedback mechanisms, the potential of accessible low-cost technologies, and the need for shared practices and standardized documentation. Building on these themes, the workshop produced four concrete recommendations to enhance the reuse and impact of marine citizen science data: (1) develop discipline-specific FAIR guidance, (2) establish minimum metadata standards, (3) create simplified training materials, and (4) support the development and deployment of low-cost sensors. This perspective article presents the EU-funded CS-MACH1 project's approach to bridging marine citizen science initiatives with European data infrastructures, and highlights the community's readiness to deliver FAIR, impactful *in situ* ocean observations.

KEYWORDS

citizen-generated data, data interoperability, FAIR data, marine citizen science, ocean observation

1 Introduction

The ocean covers more than 70% of Earth's surface, yet it remains among the most under-observed components of the Earth system. Traditional *in situ* monitoring networks, while essential, are constrained by high costs, logistical complexity, and restricted spatiotemporal coverage. Monitoring efforts are often prioritized to meet regulatory obligations, at the expense of broader observational coverage, resulting in significant observational data gaps, particularly in coastal zones, shelf seas, and remote regions.

Marine citizen science (MCS) engages thousands across Europe, spanning smartphone-based reporting to low-cost sensors on recreational vessels. Citizen-collected data can extend spatial and temporal coverage where observations are most needed, while studies have shown that such data can meet accepted quality standards when appropriate protocols, validation, and metadata practices are in place (Kosmala et al., 2016; Garcia-Soto et al., 2017; Schläppy et al., 2017; Ceccaroni et al., 2020; Earp and Liconti, 2020; Garcia-Soto et al., 2021). A recent global inventory identified over 1,260 such initiatives worldwide (Wehn et al., 2025), confirming their scale and momentum but also highlighting their “poor data management practices”, preventing these valuable efforts from being fully exploited. In our view, the field has now moved past the question of whether MCS can contribute meaningful observations; what remains unresolved, and what we argue deserves far greater attention, is how to make those contributions consistently (re)usable, interoperable, and integrated and visible within existing marine data systems.

To address these structural data challenges, the EU-funded MARine Citizen science data Horizon project (CS-MACH1) launched the Marine Citizen Science Data Network (MCSDN) by organizing a workshop. One specific action of the CS-MACH1 project is to facilitate co-designed solutions for FAIR (Findable, Accessible, Interoperable, Reusable) data (Wilkinson et al., 2016; Tanhua et al., 2019) and its integration into major data services like the European Marine Observation and Data Network (EMODnet) (Martín Míguez et al., 2019; Schaap et al., 2022; Larkin et al., 2025).

In this perspective, we report the workshop's key findings, co-produced recommendations, and MCSDN's forward-looking roadmap, affirming MCS readiness to deliver impactful *in situ* ocean observations.

2 The workshop

The event took place over two half days on February 3-4, 2026 in Ostend, Belgium, hosted by the Flanders Marine Institute (VLIZ) and led by the Swedish Meteorological and Hydrological Institute (SMHI). Over 350 individuals registered globally. The hybrid workshop brought together 30 participants in person and 170 online from 30 countries. The on-site participants were selected among the registration pool to represent a balance across disciplines, activities (MCS initiatives, data management experts, technology developers, researchers, policy practitioners) and European nations (participants attendance was self-funded, limiting broader global representation).

The program¹ was designed to first build shared context and showcase the diversity of the network community, before moving toward the co-design of practical recommendations for MCS data management and interoperability. The workshop combined presentations, case studies, live polling, and community discussions focused on FAIR MCS data, ocean data management, and the integration of citizen-generated observations into European marine data infrastructures. Sessions covered biodiversity, physical oceanography, marine litter, and low-cost sensing initiatives (Table 1), highlighting recurring challenges related to metadata, standardization, validation, and fragmented data flows. Interactive discussions and polling exercises were used throughout the workshop to identify common priorities, expectations, and barriers across participating communities.

The second day focused on practical data integration pathways through case studies following MCS data from collection to aggregation within European services. These included physical oceanographic observations from low-cost sensors via the Scuba Network, marine biodiversity observations integrated through EMODnet Biology and the European Marine Observation and Data Network Biological Information System (EurOBIS); and marine litter monitoring activities of the Sail & Explore Association linked to EMODnet Chemistry. The workshop concluded with the formal launch of the MCSDN. Live polling outputs informed the thematic analysis and recommendations presented in this paper.

3 Key themes and findings

The workshop generated a rich and diverse set of themes that cut across the four core communities represented within the MCSDN: MCS initiatives, low-cost technology developers, data management experts, and marine research institutes/data users. Each of these groups brought different perspectives and constraints, but the discussions consistently returned to common challenges and shared opportunities. The themes outlined below emerged through plenary sessions, discussions and live polling exercises.

3.1 The data quality trust gap

A persistent challenge was the “trust gap”: the reluctance of established scientific communities to integrate citizen science data due to quality concerns. The workshop challenged this framing, establishing a consensus that consistent, well-described data with documented limitations is more valuable than undocumented high-precision data. This shift from ‘quality control’ to ‘quality description’ fundamentally reshapes data workflow design.

The live polling question on support needs² confirmed that this “trust gap” is broadly felt across the community: participants ranked

1 <https://cs-mach1.eu/news-events/cs-mach1-marine-citizen-science-data-network-workshop-s-agenda-is-online-join-us-on-the-3-4-february-2026>.

2 The question was ‘Rank, from most to least, the areas you need support for’. Areas to rank were ‘data validation/quality’, ‘data interoperability/FAIRness’, ‘citizen engagement’, ‘links to policy frameworks’ and ‘usage of low-cost devices’.

TABLE 1 List of participants activities presented during the workshop covering the following categories: MCS initiatives, data management, technology development/use and research.

Category	Name	Website
Data management	EMODnet Biology	https://emodnet.ec.europa.eu/en/biology
MCS initiative	Explore Your Shore!	https://exploreyourshore.ie/
Technology development or use	MINKA platform used in SeaWatch-B	https://minka.vliz.be/
Research	Marine BioBlitz in the Baltic Sea	https://bioecoocean.org/marine-bioblitz-gotland/#english
Technology development or use	Eyeonwater app	https://eyeonwater.org/
MCS initiative	Lémanscope	https://lemanscope.org/
MCS initiative	COCAL: Citizen science and crowdsensing	https://cocal.ogs.it
MCS initiative	Sail & Explore Association	https://www.sailandexplore.com/
Data management	Litter data management in EMODnet Chemistry	https://emodnet.ec.europa.eu/en/chemistry#marine-litter
MCS initiative	Scuba Network	https://scuba.network/
MCS initiative	Citizen Science for our Ocean	https://www.germanoceanfoundation.org/citizen-science
Technology development or use	MeteoTracker	https://meteotracker.com/
Technology development or use	EnvLoggers and Coupled Temperature and Biodiversity Observation Network (CCTBON)	https://electricblue.eu/temperature-envloggers , https://www.coastalwarming.com/cctbon
MCS initiative	Educational Passages	https://educationalpassages.org/
MCS initiative	Spot the Alien	https://www.um.edu.mt/research/oceanography/malta/projects/spot-the-alien/
Technology development or use	InterBox	Martinez-Osuna et al., 2025

data validation and quality as their greatest support need, ahead of data interoperability, citizen engagement, policy connections, and device guidance. Participant presentations reinforced this finding further, with speakers independently citing sampling bias, verification backlogs, quality control challenges, missing metadata fields, standardization, and data uncertainty as recurring pain points. Relatedly, the workshop identified sensor accuracy as a real but manageable challenge, provided that both the sensor and its accuracy can be properly documented through metadata.

3.2 FAIR data as a foundation for integration

Our approach is grounded in the broader international Open Science framework, specifically the UNESCO Recommendation on Open Science³ and the European Commission's Open Science strategy⁴. Both frameworks advocate for openness “as open as possible, as closed as necessary,” explicitly recognizing that ethical standards and sensitive data often require restricted access—a reality central to MCS. Within this context, FAIR principles emerge as the most effective operational mechanism. Accordingly, FAIR formed the conceptual backbone of the workshop's technical sessions, with speakers exploring their domain-specific implications across physics, biology, and chemistry.

Participants confirmed the importance of this theme: data interoperability and FAIRness ranked second in the live polling

question on support needs², just behind data quality. Reflections collected at the end of the first day in response to the question “What have you learned today?” showed that the topic strongly resonated with participants. Many noted that they had discovered others were facing similar FAIR challenges and identified more opportunities for interoperability and collaboration than they had anticipated.

Discussions emphasized that FAIR implementation should be approached progressively, beginning with the capture of essential metadata during data collection and expanding documentation practices over time. Sessions on the second day provided practical examples of this approach across different domains. For physical parameters, discussions highlighted the importance of collecting a small set of core metadata, such as sensor identifiers, standard coordinates and timestamps, and controlled variable names, to support scalable data ingestion. Biological observations focused on standards such as Darwin Core and the World Register of Marine Species (WoRMS), while automated capture of time and location data by apps was presented as a way to simplify workflows. Sessions on chemical and litter parameters emphasized the value of structured templates, simplified mandatory fields, and validation tools to support consistent, machine-readable data collection, even in large-scale volunteer projects.

3.3 Fragmented data flows and disconnected communities

One of the most striking findings to emerge from the workshop was the extent to which MCS data collection, management, storage, and reuse remain deeply fragmented. Presenters described this fragmentation through recurring operational challenges, including

³ <https://www.unesco.org/en/open-science>.

⁴ https://research-and-innovation.ec.europa.eu/strategy/strategy-research-and-innovation/our-digital-future/open-science_en.

incompatible formats and platforms, inconsistent protocols, missing metadata, and verification backlogs. These operational barriers were closely connected to a broader perception among participants that MCS initiatives often remain isolated from one another, limiting opportunities for collaboration, interoperability, and shared learning. Dozens of live polling⁵ responses confirmed these concerns: participants repeatedly expressed a desire to discover existing initiatives and their practices, understand how collaboration could be strengthened, and identify pathways toward interoperability. Comments such as “to become better connected with other MCS projects across Europe,” “knowing new platforms to implement data collection and input,” and “understand the whole process, from data collection to published results” recurred across multiple contributions.

3.4 Closing the feedback loop

Participants identified volunteer retention and engagement as underappreciated operational challenges for MCS initiatives. Multiple projects reported declining participation over time, even with active communication and outreach efforts. Not seeing how the data collected is used or what insight it generates was put forward as a reason for the lack of engagement. Participants emphasized the importance of “closing the loop” by ensuring that contributors receive feedback on how their data are used and what outcomes they support. The critical importance of feedback loops, citizen trust, and sustained engagement is well-established in marine citizen science (Garcia-Soto et al., 2017; Sandahl and Tøttrup, 2020).

In our workshop context, it was identified that the lack of feedback is not merely a volunteer satisfaction issue but a structural barrier to data reuse: without visible outcomes, initiatives struggle to justify the metadata effort required for FAIR integration. Recognizing individual contributions — for example, through metadata provenance linking observations to specific volunteers while respecting the European Union’s General Data Protection Regulation (GDPR) — was discussed as one promising approach.

Additionally, presentations demonstrated that such feedback mechanisms can be fully automated. The EyeOnWater app instantly visualizes citizen observations on a global map upon upload, providing immediate validation, while the Scuba Network employs user-defined nicknames and contribution counters to offer gamified, automated attribution. These examples illustrate how embedding automated feedback loops and persistent identifiers directly into data infrastructure can sustain engagement by linking observations to visible outcomes and support FAIR integration.

3.5 Accessible low-cost technologies for marine citizen science

A defining feature of the presentations on technology and devices was the expanding landscape of accessible, low-cost tools for MCS. Presentations highlighted how affordable sensors and DIY

approaches are making it possible for schools, community groups, and hobbyists to collect meaningful ocean data at scale. Participants responded with considerable enthusiasm to this technological momentum pointing to rapid innovation and the potential to engage water sports and diving communities across Europe and beyond. Reference to the Solutions for Cost-effective Ocean Observation Platform⁶ (SCOOP) catalog highlighted the growing importance of databases for accessible low-cost and community-scale marine sensors as resources of detailed sensor information for MCS initiatives.

Participants also noted that affordable and easy-to-use technologies have the potential to connect projects operating in very different contexts, from well-funded European initiatives to resource-limited coastal communities elsewhere, allowing data and experience to be shared more equitably.

3.6 Best practices and standardized documentation

The Ocean Best Practices System (OBPS), now an Intergovernmental Oceanographic Commission (IOC) program, was presented as a means of elevating informal approaches into citable, reproducible methodologies. Workshop participants heard that fewer than ten formally documented best practices for MCS currently exist within OBPS, despite the breadth of community activity. The OBPS repository⁷ was introduced as a resource for participants seeking examples or templates to formalize their own methods.

Through discussions and live polling, participants consistently emphasized the need for shared guidance, comparable methodologies, and practical approaches to standardization. A cautionary note also emerged: standards must accommodate the reality that many MCS initiatives have been collecting data for years using their own protocols. Standardization therefore needs to remain flexible and adaptable. In biodiversity, the Explore Your Shore! initiative demonstrated how local observations collected via mobile apps are mapped to Darwin Core terms and reconciled with WoRMS to assign persistent identifiers, resolving synonyms before ingestion into EurOBIS and EMODnet Biology. The workshop endorsed a principle of minimum mandatory fields with optional extensions, together with clear guidance for mapping legacy data formats to standard vocabularies without requiring data to be recollected.

3.7 Data privacy, consent, and legal considerations

Although data privacy and legal compliance were not the central focus of the workshop, these issues emerged in discussions about citizen science apps, geolocated observations, and data governance. Participants highlighted that compliance with the GDPR remains a major concern, especially when initiatives rely on third-party platforms based outside the European Union. The example of MINKA, a European-hosted citizen science platform

⁵ The questions were: ‘What are your expectations from this workshop?’ and ‘What are your expectations from the CS data network of CS-MACH1?’.

⁶ <https://scoop-ocean.org/>.

⁷ <https://www.oceanbestpractices.org>.

and alternative to iNaturalist, illustrated how platform jurisdiction can shape data handling practices and influence initiative design.

These recurring challenges highlighted the need for a dedicated coordination mechanism capable of connecting initiatives, infrastructures, and expertise across the MCS landscape.

4 The marine citizen science data network

One of the main objectives of the Ostend workshop was the formal launch of the Marine Citizen Science Data Network (MCSDN), marking a major step toward implementing CS-MACH1's goal of bringing together MCS actors with a focus on data flows and strengthening data integration capacity. Developed under a Horizon Europe Coordination and Support Action, the MCSDN represents the project's primary legacy outcome, designed to continue serving the community beyond the funding period. Its central purpose is to facilitate knowledge exchange around MCS data by connecting initiative coordinators, data experts, technology developers, marine scientists, and other data users (Figure 1). To support these interactions, the MCSDN is accompanied by an online hub⁸ that serves as a directory and entry point to existing resources, guidelines, tools, and training opportunities hosted across partner infrastructures and community platforms. In the post-project phase, this hub is expected to evolve into a sustainable online platform supporting the network's long-term activities.

The MCSDN is conceived as an open and inclusive community with a deliberately low barrier to entry: any individual or organization with an interest in MCS data can participate. Rather than duplicating or operating above existing European infrastructures, the network is intended to strengthen cooperation across communities and guide initiatives toward appropriate data pathways aligned with services such as EMODnet and EurOBIS.

Looking beyond the CS-MACH1 funding period, a dedicated roadmap for sustainability and scalability is currently being developed to guide the network's long-term continuity. This roadmap will explore future governance models, funding mechanisms, and opportunities to expand membership while maintaining the network's inclusive and community-driven principles. Throughout the workshop, participants emphasized that the MCSDN should remain transparent, collaborative, and independent of any single institutional agenda — values expected to underpin its future development.

5 Recommendations

Building on Section 3, we propose recommendations to strengthen MCS in Europe's marine data landscape.

5.1 Adopt FAIR data principles from the outset, tailored by discipline

Applying FAIR principles should be treated as an ongoing process, essential for new initiatives and relevant for established projects seeking to enhance data accessibility, interoperability, and reuse. FAIR workflows should be adopted from the outset of MCS initiatives, while existing initiatives should also be supported in progressively aligning their practices with FAIR principles through guidance tailored to different data types, such as biodiversity, physical oceanography, and marine litter. This includes clear recommendations for data models, metadata content, and data-sharing and integration pathways into existing marine data infrastructures, ensuring that community-generated data can be reused and combined with other observation sources.

5.2 Strengthen metadata completeness and provenance transparency

Consistent metadata remains a foundation for data integration and reuse. The use of minimum essential metadata standards — including when, where, and how data were collected, who contributed to them, and the associated semantic vocabularies (e.g., WoRMS for species and taxa, Natural Environment Research Council vocabularies for variables and units, and SCOOP as a reference catalog for low-cost sensors) — should be encouraged. Such an approach should be recognized as a practical entry point aligned with core metadata standards, lowering barriers to participation while maintaining quality and interoperability. Beyond technical completeness, provenance transparency, including how and by whom data were collected, supports both attribution and confidence in citizen-generated records. Clear guidance frameworks should be developed to support and facilitate the adoption of consistent metadata practices.

5.3 Simplify engagement through accessible guidance and practical training

Data management complexity risks deterring initiatives with limited technical capacity. Guidance should therefore use plain language, practical examples, and a minimum-field approach, enabling initiative coordinators to engage without requiring specialized data science expertise. Complementary investment in training, particularly for small or grassroots groups, remains essential. Existing resources such as the OceanTeacher Global Academy and training materials developed through the International Oceanographic Data and Information Exchange (IODE)⁹ should be promoted, while targeted training materials for FAIR workflows and data integration should also be developed to support the broader community.

⁸ <https://cs-mach1.eu/network>.

⁹ <https://classroom.oceanteacher.org/> and <https://fust.iode.org/en/oceanteacher>.



FIGURE 1

Conceptual framework of the Marine Citizen Science Data Network within the CS-MACH1 project. The network serves as a central hub connecting MCS initiatives, device developers, data managers, and data users and researchers, facilitating bidirectional flows of data, standards, guidance, and feedback to enable FAIR MCS data integration into European marine data infrastructures.

5.4 Support the adoption of low-cost, community-scale sensor technologies

To maximize the contribution of MCS to long-term ocean observation, the adoption of affordable, easy-to-use sensor technologies that meet minimum essential data quality and metadata requirements — including accuracy, sensitivity, and calibration information, among others — should be actively promoted. This includes supporting communities in selecting, testing, and documenting best-practice workflows, and in linking local observations to European data services. The SCOOP sensor catalog represents a core, community-curated resource that helps initiatives identify reliable, fit-for-purpose tools without duplicating efforts.

6 Conclusion

The inaugural workshop of the Marine Citizen Science Data Network confirmed both the scale and readiness of the MCS community to contribute FAIR and interoperable ocean observations. Participants from more than thirty countries converged around shared challenges related to data quality, metadata, interoperability, feedback mechanisms, and coordination, as well as practical and achievable pathways forward.

The workshop's key finding was structural: the main barrier is not a lack of initiatives or technology, but the absence of shared

guidance, interoperable workflows, and sustained coordination. This structural gap is closely linked to a broader trust deficit in the use of citizen-generated ocean data, reflecting persistent concerns around data quality, validation, and perceived reliability. A shift from traditional notions of “quality control” toward “quality description” approaches is emerging, characterized by making data provenance, context, and limitations explicitly visible to support reuse and interoperability. The MCSDN was established to address this gap by connecting initiatives, technology developers, data managers, and data users through common standards and practical data-sharing pathways.

The recommendations presented in this paper reflect a community-driven roadmap centered on progressive FAIR implementation, transparent metadata practices, accessible training, and support for low-cost observation technologies. These priorities align closely with broader international efforts, including the IOC/UNESCO Ocean Decade Citizen Science Data Sharing Guideline (IOC/UNESCO, 2026) and the EuroGOOS White Paper on Affordable Technologies for Marine Observation (Marcelli et al., 2026), which together highlight the growing strategic importance of interoperable citizen-generated ocean observations.

Significant challenges remain, particularly regarding long-term sustainability, coordination, and community engagement. Nevertheless, the workshop demonstrated a clear demand for practical collaboration and shared guidance across the MCS landscape. The task ahead is now to build on this momentum and demonstrate, through expanding interoperable data flows and concrete use cases, that FAIR

MCS data are not only possible, but are already taking shape in practice. The ocean needs it, and the community is ready to deliver it.

Data availability statement

The original contributions presented in the study are available on the CS-MACH1 YouTube channel (<https://www.youtube.com/@CS-MACH1>). Further inquiries can be directed to the corresponding author.

Author contributions

EB: Writing – original draft, Writing – review & editing. NF: Writing – review & editing. PT: Writing – review & editing. AN: Writing – review & editing. PG: Writing – review & editing. SK: Writing – review & editing. LK: Writing – review & editing. JM: Writing – review & editing. VP: Writing – review & editing. CC: Writing – review & editing. JN: Writing – review & editing. DT: Writing – review & editing. CKo: Writing – review & editing. CKn: Writing – review & editing. CR: Writing – review & editing. JS: Writing – review & editing. AM: Writing – review & editing. FS: Writing – review & editing.

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Conflict of interest

Author PT was employed by the company MARIS B.V. Author AN was employed by the company ETT SpA|DEDAGroup. Authors JN, DT, and CKo were employed by Seascope Belgium.

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