Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

What marine citizen science does and does not do for ocean literacy in sailors

Evan Josselin

evan.josselin@sorbonne-universite.fr

Institut Jean Nicod

Research Article

Keywords: marine citizen science, ocean literacy, experiential learning, sailing, offshore marine environment, ocean sustainability

Posted Date: November 19th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11322374/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Marine ecosystems are increasingly affected by anthropogenic pressures, while public awareness of ocean-related issues remains limited. Ocean literacy (OL) has become a key objective of international sustainability policies, and marine citizen science (MCS) is often promoted as a promising means of fostering public engagement with the ocean. However, existing MCS-OL research has focused primarily on coastal contexts, leaving offshore settings largely unexamined. This article addresses this gap through Plankton Planet, a MCS project in which volunteer sailors collect plankton data for marine biologists during offshore expeditions. Based on semi-structured interviews, the analysis examines how this offshore context shapes the development of OL dimensions among participants. Findings show that scientific instruments enable participants to discover plankton, enhancing awareness of ecosystem fragility and generating strong affective responses, while living at sea more broadly fosters direct, embodied engagement with the ocean. However, this relationship is neither automatic nor uniform: engagement tends to reinforce pro-environmental attitudes among already committed individuals across participants, and dimensions such as transparency and adaptive capacity remain largely underdeveloped. Practical challenges specific to offshore data collection can also undermine participants' trust in the scientific robustness of the project. Building on this analysis, the study offers recommendations for designing MCS initiatives that more effectively support OL, including co-construction, knowledge-sharing, and attention to the material constraints of offshore environments, and highlights the broader potential of offshore maritime activities such as sailing to extend ocean literacy and sustainability engagement beyond coastal settings.

1. Introduction

The ocean is subject to significant anthropogenic pressures at both local and global scales, including plastic and chemical pollution, deoxygenation, warming, acidification, and changes in ocean circulation (Tornero and Hanke, 2016; Jacquin et al., 2019; Hays et al., 2005; Pörtner et al., 2019). Many people remain unaware that the ocean is intrinsically linked to major global issues such as climate change, food security, human health, and the global economy (IOC-UNESCO, 2023). Ocean Literacy (OL) has therefore been proposed as a key response and is now integrated into the objectives of the United Nations Decade of Ocean Science for Sustainable Development[1], reflecting a growing recognition that scientific knowledge alone is insufficient to address ocean challenges, and that stronger connections between society and the ocean are required for ocean sustainability (Payne et al., 2022).

OL is commonly defined as "an understanding of the ocean's influence on us and our influence on the ocean," described as "fundamental to living and acting sustainably" (Fauville et al., 2017). An ocean-literate person is thus someone who understands the ocean across its physical, biological, social, and economic dimensions and is more likely to adopt behaviors that support ocean protection and sustainability (Cavas et al., 2023). Initially focused on formal education and core ocean science principles (Cava et al., 2005; Payne et al., 2022), OL has since expanded to include the broader complexity of human–ocean relationships, integrating internal factors such as emotions and values as

well as external socio-political and economic contexts (Kopke et al., 2019; Stoll-Kleemann, 2019). It is now increasingly understood as both an educational objective and a broader societal process aimed at fostering societies that understand and care for the ocean (McKinley and Fradera, 2025; Treviño et al. 2026). Among the various approaches to fostering OL, marine citizen science (MCS) has been identified as a promising pathway by directly involving participants in the production of marine knowledge (Kelly et al., 2020). Emerging in the 1990s (Thiel et al., 2014), MCS remains underrepresented in the broader citizen science literature (Sandahl and Tøttrup, 2020; Schaffer et al., 2024), despite its significant growth over the past two decades (Wehn et al., 2025). This underrepresentation is partly explained by the inaccessibility of marine environments, logistical and safety constraints (Garcia-Soto et al., 2021), and the complexity of collecting and sharing marine data (Coppari et al., 2024). MCS relies on collaboration between volunteers and scientists through diverse forms of participation (data collection, monitoring, data analysis and publication). Participating in a citizen science project is considered to enhance public scientific literacy (Nursey-Bray et al., 2018), while also influencing behavior and supporting the uptake of scientific findings into policy and management (Danielsen et al., 2010; Ellwood et al., 2017).

MCS is particularly relevant for OL because many people have limited direct contact with marine environments (Cigliano et al., 2015). This disconnection is associated with reduced understanding of marine systems and lower awareness of ocean-related environmental issues (McKinley and Fletcher, 2010). Existing research on OL outcomes of citizen science participation has largely focused on formal education programmes for children and youth, such as “Blue Schools” (Boaventura et al., 2021; Mioni, 2022; Ceccaroni et al., 2023; Severin et al., 2023; Gagneur and Gagnon, 2025). However, if the main goal of OL is to advocate for ocean-related issues in school curricula to create more informed future citizens (Asikin et al. 2026), this must also apply to current adult populations. It is both unrealistic and unfair to assign the responsibility for ocean sustainability solely to future generations (Pahl et al., 2017).

Furthermore, most MCS projects target coastal systems, particularly marine litter monitoring (e.g., Falk-Andersson et al., 2019; Sauleau et al., 2021), and more rarely wetlands or mangroves (McKinley et al., 2024; Rivera et al., 2025). This coastal focus limits engagement with other marine ecosystems, and little is known about how MCS unfolds offshore or affects OL dimensions there. Projects also tend to focus on single-species monitoring (Wehn et al., 2025), often chordates (Garcia-Soto et al., 2017), with only a small proportion involving participants beyond data collection (Sandahl and Tøttrup, 2020), raising concerns that such projects position participants as “data generators” rather than fostering meaningful engagement (Kimura and Kinchy, 2016; Reiheld and Gay, 2019), potentially limiting OL development. Overall, the role of MCS in generating key OL dimensions remains insufficiently understood as few studies examine impacts beyond awareness or education, highlighting the need for a more detailed understanding of how MCS initiatives can be designed to better support OL outcomes (Wichmann et al., 2022).

This article focuses on the MCS project *Plankton Planet*[2] (PP), particularly its AtlantECO phase[3] (2022–2024), which mobilizes recreational sailors to collect plankton samples in the high seas and produce genetic and imaging data at a planetary scale (de Vargas et al., 2022). Designed to overcome the spatial

and logistical limits of traditional research cruises and to increase public awareness of plankton, the project involved thirty sailors sailing across the Atlantic Ocean using nets and sieves, the PlanktoScope (a microscope for plankton imaging), the Lamprey (a filter DNA/RNA kit), and the Curiosity (an outreach microscope). Participants follow a protocol that includes sampling plankton, recording metadata, preparing and dividing samples for imaging and genetic analysis, operating instruments, and storing both images and biological material.

PP provides a valuable case study for examining OL among adult sailors engaged in offshore MCS. It is also focus on plankton, a comparatively understudied subject within public outreach initiatives (Tara Ocean Foundation et al., 2022). Semi-structured interviews were conducted with participants after completing their scientific voyages, providing qualitative data on their experiences. Two research questions guide the analysis: (1) To what extent do sailors already exhibit OL, and which dimensions are most developed? and (2) Does participation in PP contribute to the development or reinforcement of participants' OL, and is the offshore context shaping in a particular way this development? The analysis draws on the framework proposed by McKinley, Burdon, and Shellock (2023). Applying this framework to PP allows for a systematic examination of how MCS participation relates to different dimensions of OL.

In doing so, this study contributes to ongoing debates on how OL can be more effectively conceptualized and supported through MCS, and identifies levers for designing MCS projects that more effectively foster OL, with implications for marine conservation and sustainability policy.

2. Methods

To study OL in PP, the analysis draws on the framework developed by McKinley, Burdon, and Shellock (2023), which moves beyond earlier knowledge-centred approaches and offer a more holistic model of OL. Table 1. is illustrating how MCS can contribute to the different dimensions of their OL framework.

Table 1
Summary table of the potential contribution of marine citizen science to ocean literacy

Ocean literacy dimension	**Contribution of Marine Citizen Science**
Knowledge	Deepens understanding of marine ecosystems through participation in scientific activities.
Awareness	Increases awareness of marine environmental challenges by involving participants directly in scientific research.
Attitude	Shapes environmental attitudes, including support for ocean-related policies and conservation measures.
Trust and Transparency	Enhances the trust that people place in marine science and sources of ocean information, offering transparency by increasing familiarity with marine science methods.
Behavior	Encourages more ocean-friendly behaviors (decisions, choices, actions, and habits) with respect to ocean related issues by linking human activities to marine environmental impacts.
Activism	Makes volunteers aware of current ocean challenges, leading them to engage in ocean protection actions.
Communication	Extends ocean literacy beyond participants through sharing of experiences and knowledge within families, peers, and social networks.
Adaptive Capacity	Builds capacity to understand environmental pressures and respond to change in marine systems.
EmOcean	Fosters emotional engagement with the ocean through direct exposure to marine environments.
Access and experience	Provides direct access to and embodied experience of marine environments, reinforcing participants' sense of connection to the ocean.

Although quantitative approaches are favored in OL research (Shellock et al., 2024), qualitative methods were used to study PP because they provide a more detailed understanding of participants' experiences and how different OL dimensions are enacted. Fourteen semi-structured interviews were conducted in French, each lasting approximately ninety minutes[4] and audio-recorded with participants' consent. Most interviews were conducted online via Zoom as it proved to be more logistically efficient, while three took place in person. Participants were recruited during end-of-trip feedback sessions organized by the PP operational team. Participation therefore followed a convenience sampling approach. Given that theoretical saturation in qualitative research often occurs within the first twelve interviews (Guest et al. 2006) and that half of the sailors were interviewed, the sample size can be considered adequate for the purposes of this study.

Interviewees included participants from all five vessels equipped with PP scientific instruments, which provided access to accounts of data collection activities across each boat. Six interviewees were experienced sailors who had served as skippers during the expedition or at other points in their lives. All

had started sailing at a young age; two had participated in offshore racing competitions, two had worked as sailing instructors, and two primarily sailed recreationally with friends or family. The remaining eight participants had not grown-up sailing, and their time spent on sailboats ranged from a week to approximately one month. The sample therefore includes two distinct groups of participants: experienced sailors for whom sailing has been a central and long-standing practice, and newcomers to sailing who joined the expedition through their more experienced peers. This distinction allows for comparisons between participants who have different relationships to the ocean.

Interviews began with general questions about participants' backgrounds and relationships with the sea before moving to more detailed discussions of onboard data collection practices and their perception of MCS[5]. This structure helped establish trust and ensured that questions about data collection were not perceived as evaluations of data quality. Following King and Horrocks (2010), interviews were conducted as flexible and conversational exchanges rather than strictly standardized procedures. Although guided by a common interview structure, participants were encouraged to elaborate on themes they considered important.

For the analysis of interviews, a grounded theory approach was employed (Corbin and Strauss 1990; Charmaz 2006). Coding was conducted manually and involved the segmentation and reorganization of textual material in order to identify emerging themes. This process was carried out collaboratively with a master's student, who worked on anonymized interview transcripts. In total, twenty-four codes were established, which were grouped into three thematic clusters: collaboration between scientists and participants, participants' agency in scientific practices, and perceptions of the ocean. These codes were subsequently reviewed by an external researcher, providing an additional perspective on the coding scheme and contributing to its refinement. The grounded analysis suggested that OL provides a relevant framework for interpreting the empirical material in relation to MCS. The codes were therefore compared with the OL framework developed by McKinley, Burdon, and Shellock (2023). This made it possible to assess participants' OL by identifying which dimensions were present in the data and which were absent or less developed.

This study has several methodological limitations. First, some participants could not be interviewed because they were absent from the end-of-trip feedback sessions. According to other crew members, these participants sometimes felt they had not correctly collected data and therefore did not consider their experience worth discussing, which likely led to the underrepresentation of less confident perspectives. A second limitation is the absence of direct observation of participants' experience at sea as it was not possible to join the expeditions. The analysis relies on retrospective accounts collected two to six months after the trips. This introduces potential recall bias, although it is partly mitigated by interviews conducted with participants from all five sailboats and by cross-checking accounts from multiple crew members on the same vessel. The time lapse still allows insights into what remained salient after the expeditions. Finally, no pre-expedition interviews were conducted due to participants' logistical constraints before departure. This limits the ability to systematically assess changes in OL

over time, although participants did provide retrospective descriptions of their prior knowledge and relationship to the ocean.

3. Results

3.1. Access, awareness and experience of the ocean through sailing

The first dimension of OL visible in sailors' experiences concerns direct *access to*, *experience of the ocean* and *awareness* through extended periods at sea. Interviews reveal the intensity of these encounters with the marine environment, particularly among participants with limited prior sailing experience. When asked about their expectations before joining the voyage, one participant explained:

"Well, basically, I decided to go because it was a new adventure. […] But I didn't expect to experience something so deeply connected to the sea, the element itself. I don't know how to put it… And, um… that was really powerful too". [D_Real]

One participant emphasized that "this link to the elements" "puts [her] in [her] place as a tiny living being on a much vaster earth" [A_Real]. Through sailing, participants thus appear to become more aware of their position within the ocean as a dynamic system that extends beyond their own personal circumstances. Another participant, much more experienced in sailing, offered a particularly detailed description of this awareness:

"You're in a calm spot—there's no wind around you, the sea is like oil, and all the birds are gliding over the waves, or rather, using all the updrafts created by the swell so they never have to flap their wings while flying. It's just so beautiful. At that moment, I really thought to myself, 'Wow, this is amazing.' I'm really lucky to be here and to be surrounded by all of this". [A_Boug]

A second element within these dimensions relates to *the experience of sailing itself*. Sailing involves a unique relationship to time and social interactions. Four participants described sailing as a "lifestyle", emphasizing that the journey itself constitutes a meaningful experience. One participant articulated this perspective particularly clearly: "I think that for me, sailing is mostly this: a different approach to how you live day-to-day on your boat, and also how you travel, how you meet people". [C_Real]

Finally, several participants described the sailboat as a social and affective space. Three participants referred to the boat as a "cocoon" and a form of "family", highlighting the sense of intimacy and shared experience created during long voyages. One participant described her sailboat as a "platform" that should remain open to others, allowing encounters between people with different points of view [C_Ada].

3.2. Sailors EmOcean

Implementing the PP protocol and using its scientific instruments enabled participants to discover plankton firsthand, an experience that proved highly impactful and elicited a wide range of emotional

responses captured by the “EmOceans” dimension, including complex affective experiences such as astonishment, admiration, awe, belonging, and empathy. The primary emotional reaction reported was *astonishment*, particularly in response to the remarkable diversity of planktonic species. One participant captured this feeling, stating: “I think it’s something that strikes everyone, every time, the number of different species you see, the way each of these species moves” [D_CNRS]. Participants also expressed *awe* for the aesthetic beauty of plankton: “I was like a kid discovering a whole new world. I found it... I was in awe. It seemed incredible to me that all those tiny things made up, I don't know, such a huge portion of marine biomass” [C_Real]. These microorganisms, with their multiform structures, intricate symmetries, and sometimes monstrous appearances, elicited wonder and fascination. As another participant described: “It’s a universe in itself that you discover; there’s something fascinating about it” [A_Boug].

For several participants, EmOceans took the form of a felt sense of *interconnectedness* between plankton, oceanic ecosystems, and human life. For example, one participant emphasized that the ocean, which is often perceived as empty, is actually teeming with life: “I realized there was life out there—even in those parts of the ocean where you don’t see any fish, you don’t see any dolphins, you don’t see any whales, but there’s still an incredible amount of life. Everywhere, everywhere, everywhere.” [A_Real]. Another participant reflected on how discovering plankton ecological significance had broadened their understanding of life and fostered a sense of belonging to a larger web of living beings, beginning with plankton:

“For me, it’s something that really touches me deeply—life, you see […] this deep sense of my connection to life, which was incredibly strong—that web of relationships that I ultimately consisted of, you see, and nothing else. So from there, you feel that plankton is part of your family, you see. […] Well, if the plankton isn’t there, in a way I’m not really there either, you see.” [B_Ada].

This strong emotional connection with plankton also gives rise to *empathy* toward the organisms being observed, as the same participant explained:

“Yeah, because you see, it kind of hurt my heart. I didn’t tell you, but… in fact, you collect plankton, but you destroy it at the same time. And I tell myself, it’s always these confrontations … what you accept for science, what you don’t accept, your impact…”. [B_Ada].

Shortly afterward, they recounted feeling compelled to release a fish larva that had hatched from an egg observed under the PlanktoScope.

3.3. Sailors’ attitudes, behaviors and activism

The interviews revealed no major changes in participants’ attitudes toward ocean protection, as most already held pro-environmental views and joined PP to support marine research and conservation. As one participant explained: “We wanted it to have a purpose—in other words, a real project—so it wouldn't just be a trip, and so there would be a connection to research [...] to help where help is needed” [B_Real].

All participants emphasized that the voyage should go beyond “personal leisure” by contributing to research and, more broadly, to efforts addressing climate change and ocean degradation.

For participants whose pro-environmental attitudes were still developing, living at sea revealed the ocean's current state in a direct, experiential way rather than as an abstract issue:

“There's the whole experience of living on the ocean and seeing firsthand everything that's going wrong. That we can catch less fish, that it's really hard to catch even a single fish after spending a whole week out on the water. [...] There are so many things that affect you when you live on the water.” [D_Real]

Another participant described a gradual shift away from sailing races: after years of pushing for speed and performance, he began to question whether he was fully appreciating the environments he navigated—a reflection that eventually led him toward PP:

“Back when I first started crewed sailing, it was all about the technical side—full-on racing, pushing the limits. There were dolphins, and I’d be like, “Cool, that’s nice,” but then I’d snap back to focus. […] And since then, it’s slowly grown. I feel like I’ve gone from a passion for the technical aspects of boats to a passion for the ocean, and now the technical side doesn’t carry as much weight compared to what it allows you to do and what it allows you to connect with. This realization of the ocean’s beauty is fairly recent for me, and my engagement in Plankton Planet is the result of that.” [A_Boug].

Regarding behavioral change, participants did not report major shifts in habits or everyday practices when interviewed two to six months after their expedition, though intentions for longer-term change were visible: four expressed a desire to purchase a vessel and continue MCS, and another decided to reorient his engineering studies toward the sociology of public action, with plans to research barriers to integrating scientific knowledge into public policy.

Finally, five participants were already involved in environmental NGOs or civil disobedience movements (not ocean-specific); for these individuals, their experience at sea appeared to reinforce their commitment to activism:

“All the conversations we've had here and there about chlordecone in Martinique and about environmental issues in general make you realize that this is where you want to take action. [...] I was already somewhat interested in environmental issues, but I wouldn't have realized just how important it was to me and to the world in general.” [D_Real]

The two participants who raced competitively became involved in *La Vague*, an association working to make competitive sailing more environmentally and socially responsible by highlighting its ecological costs. One of them later organized two editions (2024, 2025) of a “Plankton Festival” in Saint-Gilles-Croix-de-Vie, supported by the project's scientific team, introducing the public to plankton and raising awareness of threats to marine ecosystems.

3.4. Engaging with science at sea: implications for the trust dimension of OL

Implementing PP's protocol often proves challenging. Sailing boats are subject to specific maritime constraints: energy is sparse, spaces are damp, confined, and constantly in motion. One participant interviewed provided a concise description of the difficulties encountered when conducting scientific research on board:

"We sometimes took an hour, an hour and a half to do a sample. You put it down to go and eat and you find it's completely upside down, it's a basic careless mistake, but at the same time it happens and at sea you really have to think everything through and know exactly why you're doing what you're doing and there's no room for hesitation or error." [D_Real]

Participants also reported difficulty using the PlanktoScope. Handling the flow cells was challenging because they often broke when inserted into the microscope if one was not careful. One crew damaged all of their flow cells, which prevented them from using the instrument for the rest of the expedition.

Another key challenge in data collection at sea relates to the data collectors themselves: sailors. Aligning scientific requirements with sailors' practices and values proved complex, as everyday life on board does not easily fit the temporal demands of research. Navigational schedules often conflicted with the scientific protocol, as one participant explained: "You know, there's something I wanted to say: on a boat, contrary to what people think, there's a lot to do! You have to keep watch, you have to sleep, you have to cook, uh… maintenance, odd jobs—so you can't be 100% focused, uh… on scientific work" [A_Ada]. As a result, completing the sampling protocol in one uninterrupted sequence was difficult, even though such continuity is important for sample quality (to prevent biological changes such as zooplankton consuming phytoplankton). Sailors had to balance scientific tasks with navigation, rest, meals, maintenance, and repairs, while fatigue from watch shifts further limited their capacity to handle equipment carefully:

"This concept of energy on board—which you don't really experience as much on land—is that your energy is limited by your shifts; you don't have much energy during the day, so you're exhausted by evening. Even though it didn't take you very long, it still took a lot of energy to carry out this experiment" [D_Real].

This context led to occasional mistakes such as spilling samples, forgetting filtration steps, or prematurely shutting down equipment, which participants generally attributed to the constraints of life at sea rather than negligence.

Furthermore, the time demands of the scientific protocol sometimes conflicted with the contemplative nature of sailing. As one participant explained: "You have many moments when you do nothing on a boat, and it's important to do nothing. It's about communing with the sea, saying nothing and doing

nothing" [D_CNRS]. Four participants in particular highlighted this tension between the demands of the protocol and the experiential dimension of sailing.

This context affected participants' confidence in the quality of the data they produced. One participant explained: "I think there's always been this question between us about… But is our data… is it even usable? Because we didn't have… I mean, there was never a moment when we felt like there was any validation to say, 'Okay, now it's certified,' or that it's scientifically usable." [B_Real]. This concern was reinforced by the lack of immediate feedback from instruments and scientists, as data quality is only assessed months later on land. One participant explained: "Maybe the thing that disconnected me a bit from plankton and from Plankton Planet is that I don't really know what I'm looking at in the end, or where things stand now with our data… I don't quite manage to project what my data, what we did, is doing today." [A_Real].

For six participants the difficulties encountered in producing scientifically robust samples negatively affected their attitudes toward science and had implications for their trust in the scientific process. One participant explained during an interview: "There were times when it felt a bit like tinkering. When we were assembling the flowcell on the microscope on the boat that was swaying, and I was feeling a bit seasick, I didn't find it very scientific." [B_CNRS]. It has discouraged some participants, reinforcing the perception that they were not producing "good" science. Another interviewee expressed this concern, stating: "The approximations we made when following the protocol led us to question the seriousness and credibility of the endeavor." [D_Real]. A form of mistrust toward their results—and sometimes toward the scientists involved in the project—thus emerged in some participants' accounts, with one participant asking "Who is the scientific authority?" [B_Real] in the project.

3.5. Sailors' relation to plankton knowledge and its communication

Following their participation in PP, most participants reported an increase in their knowledge about plankton, as many of them had little or no prior familiarity with this group of organisms. Prior to the expedition, their understanding was generally limited to the idea that plankton were "small creatures drifting in the sea" or "little shrimps," as described by several interviewees.

Beyond acquiring a basic definition of plankton, participation in PP allowed sailors to develop an understanding of plankton concentration within seawater samples. As one participant explained: "We saw a lot of plankton, so that gives us an idea of the ratio—uh… the ratio of one species to another—since we can see them passing by" [A_Ada]. Another participant came to view plankton as a fragile community of living organisms that might require protection rather than as an abundant and resilient resource:

"In the end, I imagined plankton as much more concentrated than that. […] I thought there were huge, huge numbers of them. And then it hit me that we had to fish for half an hour and filter thousands of liters of water just to end up with a sample that was pretty small, in my opinion. To me, if a species isn't

abundant, it's bound to be fragile. Actually, it always makes me think of all those species that end up disappearing because there aren't enough of them left" [B_CNRS].

However, participants did not appear to develop in-depth knowledge of plankton species or their ecological roles. It remains unclear whether images produced by the instruments supported further learning, as several participants reported difficulty recognizing plankton based on morphology alone. Many plankton organisms display similar forms even at the group level, and the relatively small size of the digital images makes distinguishing details challenging[6]. Some participants referred to *Wonders of the Drifting World* (Sardet, 2015), a book recommended by the PP team that combines microscope images and explanatory text:

"But after that… even today I don't really know much about plankton. I have a bit more of an idea of its overall importance in the marine world and in the global balance. I would be incapable of standing in front of a class, even children, and explaining plankton to them. […] Very quickly I would end up looking at the book [Sardet's book] with them and saying, 'Oh, it's beautiful!'" [A_Real].

This difficulty was emphasized by six other participants. One participant, for instance, highlighted the challenge of "making the link between the very pretty photos I could see [in Sardet's book] and the rather ugly photos we were taking [with the PlanktoScope]." [E_Real]

These observations do not, however, indicate a lack of interest among participants in developing knowledge about plankton. Among the fourteen participants interviewed, five did not mention the issue explicitly, one reported having independently learned more about plankton during the crossing because they found it fascinating, and eight expressed a clear desire to learn more. One participant expressed this: "What are we actually seeing? […] I need to know what these little things are, what they're for, how they live, at what moment… at what point in the chain they are… that's it." [A_Ada] Another participant explained: "The first time I saw plankton, I found it impressive. But then it was the same thing. So I didn't feel like doing it an nth time. […] And then even if I see a new plankton, I'll just say to myself, 'Ah, that's a plankton I don't know.' And then?" [E_Real].

Participants also linked their desire for plankton knowledge to how they can communicate about it: not knowing what they had observed generated frustration in social situations, particularly when questioned in port. As one participant explained: "What we were missing was having things to say when we arrived. [...] It's super frustrating to have nothing to say." [C_Real]. Six participants suggested that simple interpretive outputs from the instruments—basic graphs or short descriptions of dominant plankton types—would have improved their ability to communicate their observations. One crew organized outreach workshops during stopovers, inviting schoolchildren to create a "plankton fresk" and observe samples through the Curiosity; preparing these sessions appeared to deepen their own understanding, as one participant noted: "that's what really pushed us... to learn about plankton because we had to have things to tell the classes." [A_Boug]. More broadly, participation generated discussions with family and friends after the expedition, and, for some, extended to professional networks via LinkedIn[7].

4. Discussion and implication for future research

4.1. Offshore sailing and marine citizen science as complementary contexts for ocean literacy

Participation in a MCS project such as PP may contribute to the development of several dimensions of OL among participants. First, the experience of life at sea on a sailboat appears to be central, particularly for less experienced sailors, for whom life offshore was a first extended and immersive encounter with the marine environment. It meant learning to inhabit an environment that differs radically from terrestrial spaces. In interviews, participants described the distinctive sensory and material conditions they had to experience: the relative scarcity of energy and resources, the pervasive humidity and salinity, the physical confinement of the vessel, and the constant motion of the sailboat. Sailing therefore involves not simply moving through the ocean but learning to live within and respond to a particular environment, generating forms of embodied knowledge that may be difficult to acquire through more intermittent contact with the sea. It also gave participants time to become more attentive to their relationship with the ocean and to the ways human activities shape marine environments. For more experienced sailors, this relationship did not appear to become merely routine: they still described sailing as a powerful and awe-inspiring experience, with each crossing offering an opportunity to renew their sense of wonder. From this perspective, experienced sailors may already possess several dimensions of OL, particularly access, awareness, and experience of the ocean, which may in turn be reinforced through their continued engagement with the sea. These findings are consistent with Reason's (2016) argument that sailing vessels can create opportunities for intimate engagement with the marine environment and alternative experiences of space and time. Morgan and Braungardt (2025) also highlight that sailing is a "convivial mode of existence" in which everyday practices at sea can foster forms of resilience and sustainability that resonate with the principles of OL. This was also visible during PP expeditions, when several participants described the vessel as a "cocoon," pointing to the intense social and environmental immersion of life offshore and to the social dynamic it establishes.

Across participants with different levels of experience, accounts suggest that extended time at sea fostered awareness of being embedded within a dynamic ocean system, connecting what they observed, what they knew, and their own position within it. This form of systems thinking—recognizing relationships among components of a system and how changes in one may affect others (Assaraf and Orion, 2005)—is particularly relevant to understanding complex environmental objects like the ocean. Participants, for instance, grew more attentive to causal relationships between activities such as fishing and changes in marine life, and could directly observe environmental variability—weather, waves, light—altering their surroundings throughout their journeys.

Interviews with the participants suggest that the offshore context is an important condition for the development and reinforcement of OL (particularly the dimension of access, awareness, experience of the ocean and EmOcean). Its contribution seems to lie less in the amount of contact with the ocean than in the nature of that contact, which requires participants to inhabit, observe, and adapt to the marine

environment over extended periods. Testing this would require a systematic comparison between offshore and coastal sailing, which future studies should undertake.

Nevertheless, the findings also caution against treating sailing itself as a straightforward pathway to OL. Several participants pointed out that sailing can involve environmentally unsustainable practices and that some sailors may be primarily concerned with technical performance, such as speed, rather than with developing a deeper relationship with the marine environment. Proximity to the ocean, and prolonged exposure to it, therefore does not necessarily result in pro-environmental behaviors. This observation is consistent with research on other ocean-based recreational activities, such as surfing (Whyte, 2019; Fox et al., 2021).

Second, the citizen science dimension of the project was also important for the development of OL among participants. By introducing specific practices of plankton collection and observation, it directed participants' attention towards aspects of the marine environment that are largely imperceptible during ordinary sailing. Several participants described realizing that offshore waters that had initially appeared devoid of life were, in fact, teeming with organisms. Direct observation of plankton thus made the otherwise invisible biological richness of the ocean perceptible, increasing participants' awareness of the diversity and vulnerability of microscopic marine life. It also appeared to foster "EmOcean" and a heightened awareness of the interconnectedness between humans and marine organisms. Participants described developing feelings of belonging and attachment towards the plankton they encountered through the project. For one participant, this connection took on an almost spiritual dimension, as he described plankton as becoming "part of [his] family." This illustrates how direct engagement with plankton could contribute to a relational understanding of the ocean, in which humans and non-human organisms are perceived as interconnected and interdependent. It converges with Tugend's (2025) account of OL as encompassing a deep and reciprocal relationship between humans and the ocean. In PP, participants' perception of this relationship emerged from the combination of direct observation, participation in scientific practices, and sustained exposure to the marine environment.

Third, most participants already held pro-environmental attitudes toward the ocean, which is part of why they decided to join a MCS project. These attitudes nevertheless appeared to be reinforced through the project among participants whose environmental awareness was more recent. Participants reported that encountering marine pollution or observing the exploitation of ocean resources during offshore navigation deepened their environmental concerns. Exposure to the diversity, beauty, and fragility of plankton increased their awareness of its ecological importance. It fostered a stronger sense of responsibility toward marine life, extending participants' moral consideration to planktonic biodiversity. In this sense, PP appears to have strengthened the attitudinal dimension of OL among sailors, leading them to consider the ocean not only as a space for sporting activity but as an ecosystem demanding respect and care.

Finally, the activism dimension was already present among some participants, and PP reinforced their conviction that continued engagement was necessary; roughly half, however, did not engage in new

forms of activism. Participation in PP thus appears to reinforce existing commitments rather than generate new activism—a finding that warrants further investigation through long-term studies. It is plausible, though, that dimensions such as EmOcean and awareness affect pro-environmental behaviours over time rather than only attitudes: Lotze (2020) and O'Halloran (2025) links positive emotions (gratitude, awe, joy) to ocean conservation stewardship and care.

These findings point therefore to a potentially complementary relationship between sailing and MCS. Offshore sailing provides an extended and embodied context for engaging with the ocean, while MCS can structure this engagement around the observation of micro-organisms and the production of knowledge, thereby contributing to the development or reinforcement of OL dimensions.

4.2. Constraints and unintended effects on OL

Interviews also reveal constraints that may limit OL development in PP. First, the interplay between the ocean, sailors, and science proved challenging, as participants had to operate complex instruments under difficult conditions at sea. As a result, participation in scientific activities did not strengthen the trust dimension: some participants reported reduced confidence in the project's scientific robustness and methodological reliability, and questioned scientists' authority in the project. Although citizen science is often seen as fostering trust between scientists and the public (Spellman, 2014; Strasser et al., 2019), it can instead be weakened when instruments, sampling protocols, and navigation conditions are not aligned. Trust was also affected at the level of participants' confidence in their own contribution: some declined to be interviewed because they felt they had failed the project by being unable to collect data correctly. As a result, the project loses their feedback, which also reduces the likelihood of their taking part in future projects. Trust took on a different meaning for one participant, who described a complicated relationship with science after having to "kill" plankton in order to observe it, which led them to question what should be accepted in the name of science. This illustrates an ethical tension around how science is done and to what end, one that can erode participants' trust in science itself. These findings on trust suggest that this dimension of OL deserves closer examination, as it is less straightforward than it may appear: at least three distinct meanings of trust are at stake here — trust in the scientific credibility of the project, participants' trust in their own contribution, and trust in the ends and means of science. This raises the question of how the development of OL relates to trust, and specifically to which of these meanings, as well as whether all three matter equally for OL.

For trust as scientific credibility, collaborating from the outset to integrate sailors' navigational knowledge with a scientific understanding of plankton sampling may have helped maintain trust. Future MCS initiatives could place greater emphasis on the co-construction of scientific protocols and instruments. Kelly et al. (2022) point out that methodological design is often a point where translation between actors in citizen science limits the quality of participation, and Turcati et al. (2022) note that, although co-construction is often highlighted in the citizen science literature, it is not common in projects primarily focused on data collection. Co-developing methods with participants could help ensure scientific rigor under real-world conditions and allow more in-depth, two-way interaction between scientists and participants. Such an approach implies a shift from a top-down contributory model

(Bonney et al., 2015) toward more collaborative forms of participation, even in data collection projects. Interestingly, this also implies that classical typologies of citizen science, based on participants' level of involvement, fail to capture the full scope of the research process in these projects and it could be an answer to criticism raised in the introduction, that participants are mere “data generators”.

Second, the knowledge dimension of OL was only partially developed. Participants reported acquiring a basic understanding of what “plankton” refers to and of its concentration in the ocean—not insignificant, since, as the Plankton Manifesto (2024) emphasizes, such knowledge remains relatively uncommon among the public. The use of microscopes, particularly in situ observation of plankton, played an important role in this process by generating emotional engagement with the ocean (EmOcean) among participants (see above). As Dewey (1938) suggests, emotions can drive knowledge development. Here, this emotional engagement contributed to the emergence of “plankton literacy,” which is identified as a key prerequisite for public understanding of plankton’s role in climate regulation and of the global impacts of climate change (Shemi et al., 2026). But emotion alone was not sufficient: without aiming to turn participants into marine biologists, many expressed a desire to learn more and frustration at not fully understanding their results, often because they struggled to explain their observations to others, particularly when questioned in port. This points to a strong interdependence between the knowledge and communication dimensions of OL: participants who shared knowledge with local communities described this communicative role as an incentive to learn more about planktonic ecosystems, their ecological importance, and the need for their protection, and became science communicators, acting as intermediaries between the scientific team and the publics they encountered. These findings suggest that communication can play a central role in motivating participants to expand both their scientific understanding and their ability to translate complex ocean-related issues into accessible narratives. Supporting participants therefore appears important not only for data collection, but for helping them communicate their work and develop their own questions as they learn.

Third, the behavioural dimension remains difficult to assess, despite being a central objective of OL (Ashley et al., 2019), with studies highlighting the methodological challenges of evaluating long-term behavioural effects of MCS (Somerwill and Wehn, 2022; Morgan and Braungardt, 2025). Although most participants did not report immediate behavioural changes, some indications suggest that participation in PP may influence personal trajectories: one participant wanted to pursue studies related to public action, another became involved in a sailing association (see above), and several planned to acquire a vessel to continue participating in MCS. However, the temporary nature of participation in projects such as PP may limit the durability of such transformations, particularly for issues like plankton that remain distant from everyday experience. At the same time, McKinley et al. (2024) show that immersive experiences can foster intentions toward long-term behavioural change. Gomez et al. (2025) argue that knowledge alone is insufficient to transform the human–ocean relationship and emphasize the importance of values, beliefs, and social norms in shaping pro-environmental behaviour. This resonates with one participant’s account, in which participation in PP transformed their understanding of what sailing should represent and led them to create a plankton-themed festival promoting awareness of plankton ecology and ocean protection. This example suggests that a project such as PP may foster

behavioural change when it strengthens personal and cultural connections with the ocean and encourages participants to see themselves as part of potential solutions.

Finally, two dimensions of OL did not appear. The transparency dimension, which concerns access to information and openness in ocean-related knowledge, was largely absent, as the project did not involve participants in disseminating results through public platforms or publications. The adaptive capacity dimension, understood as the ability of a community to respond proactively to change, stressors, or opportunities, was not an explicit objective of the project.

4.3. Recommendations for strengthening ocean literacy through marine citizen science

Although based on a single case study, these findings may extend to other MCS projects: science and ocean experience are not easily combined, yet together offer multiple opportunities for OL. The following recommendations, summarized in Fig. 1, address both how to strengthen OL through MCS and which dimensions warrant further research.

Ocean materiality

Taking ocean materiality into account is particularly important: designing protocols and instruments adapted to offshore conditions helps overcome practical obstacles, while leveraging EmOcean through sensory and aesthetic experiences at sea fosters a lasting emotional connection to the ocean.

Developing trust and knowledge-sharing practices

Co-constructing instruments and protocols with participants could build trust from the outset while clarifying their values, needs, and experiential knowledge—which itself matters for the sustainable management of ocean resources (Kelly, 2018; McKinley, Burdon, and Shellock, 2023; McKinley and Fletcher, 2012). Participants who trust the science produced are also more likely to advocate for its results and engage in civic processes shaping ocean policy. Strengthening knowledge-sharing practices could further help participants interpret and communicate their observations, potentially as science communicators, and reach communities without regular ocean contact, since sailing remains a largely privileged activity (O'Connor, 2024).

Directions for future research

First, framing expeditions as entry points into sustained participation—through participant networks and ongoing opportunities for contribution—could support longer-term engagement and adaptive capacity, by linking data collection more closely to participants' lived experience of the ocean. Second, although trust proved important for PP's functioning, few studies examine its relationship to OL; further research is needed on how to build trust with non-scientist publics, closely tied to transparency that goes hand in hand with improving feedback mechanisms through systematic result-sharing and open-access data repositories.

Declarations

Funding: *This work was supported by the Centre National de la Recherche Scientifique, France.*

Declaration of interest statement: *The author report there are no competing interests to declare*.

Data availability statement: *The dataset and the coded interviews can be found online on the Zenodo platform: https://doi.org/10.5281/zenodo.20571336*

Clinical trial number: *not applicable*

Ethics statement: This study is a social science interview study with adult participants and did not require review by an ethics committee or Institutional Review Board under French law. The Jardé law (Law No. 2012-300 of 5 March 2012, implemented by Decree No. 2016-1537 of 16 November 2016) requires review by a Comité de Protection des Personnes only for research aimed at developing biological or medical knowledge, which is not the case here. No ethics body reviewed or exempted the study, as no review or exemption procedure applies to research of this type in France. The research was conducted in accordance with the French National Charter of Research Ethics and Integrity and the General Data Protection Regulation (GDPR), by a researcher employed by the French National Centre for Scientific Research (CNRS).

Consent to participate: All participants were adults and gave their freely given, informed consent to take part in the study, including to the audio recording of the interviews, before the interviews began by signing a letter of consent.

Consent to publish: All participants were adults and gave their informed consent to participate in the study and for the anonymised publication of the results, including excerpts from their interviews, before the interviews began.

References

1. Ashley M, Pahl S, Glegg G, Fletcher S. A change of mind: applying social and behavioral research methods to the assessment of the effectiveness of ocean literacy initiatives. Front Mar Sci. 2019;6:288.
2. Asikin N, Suwono H, Sumitro SB, Dharmawan A. Teaching ocean literacy in science education: A systematic review. Environ Educ Res. 2026;32(3):812–37.
3. Boaventura D, Neves AT, Santos J, Pereira PC, Luís C, Monteiro A, … Ponces, de Carvalho A. (2021). Promoting ocean literacy in elementary school students through investigation activities and citizen science. Frontiers in Marine Science, 8, 675278.
4. Bonney R, Phillips TB, Ballard HL, Enck JW. Can citizen science enhance public understanding of science? Public Underst Sci. 2015;25(1):2–16. https://doi.org/10.1177/0963662515607406. (Original work published 2016).

5. Cava F, Schoedinger S, Strang C, Tuddenham P. (2005). Science content and standards for ocean literacy: A report on ocean literacy. https://coexploration.org/oceanliteracy/documents/OLit2004-05_Final_Report.pdf
6. Cavas B, Acık S, Koc S, Kolac M. Research trends and content analysis of ocean literacy studies between 2017 and 2021. Front Mar Sci. 2023;10:1200181.
7. Ceccaroni L, Woods SM, Butkevičienė E, Parkinson S, Sprinks J, Costa P, Piera J. The role of citizen science in promoting ocean and water literacy in school communities. ProBleu Methodol Sustain. 2023;15(14):11410.
8. Charmaz K. Constructing grounded theory: A practical guide through qualitative analysis. sage; 2006.
9. Cigliano, J. A., Meyer, R., Ballard, H. L., Freitag, A., Phillips, T. B., & Wasser,A. (2015). Making marine and coastal citizen science matter. *Ocean &; Coastal Management*, *115*, 77–87. https://doi.org/10.1016/j.ocecoaman.2015.06.012.
10. Corbin JM, Strauss A. Grounded theory research: Procedures, canons, and evaluative criteria. Qualitative Sociol. 1990;13(1):3–21.
11. Coppari M, Roveta C, Di Camillo C, Garrabou J, Lucrezi S, Mantas P, T., Cerrano C. The pillars of the sea: strategies to achieve successful marine citizen science programs in the Mediterranean area. BMC Ecol Evol. 2024;24(1):100.
12. Crawley SL. Gender, class and the construction of masculinity in professional sailing: A case study of the America3 Women's Team. Int Rev Sociol Sport. 1998;33(1):33–42.
13. Danielsen F, Burgess ND, Jensen PM, Pirhofer-Walzl K. Environmental monitoring: the scale and speed of implementation varies according to the degree of peoples involvement. J Appl Ecol. 2010;47(6):1166–8.
14. de Vargas C, Le Bescot N, Pollina T, Henry N, Romac S, Colin S, Haëntjens N, Carmichael M, Berger C, Le Guen D, Decelle J, Mahé F, Poulain J, Malpot E, Beaumont C, Hardy M, Guiffant D, Probert I, Gruber DF, Prakash M. (2022). Plankton Planet: A frugal, cooperative measure of aquatic life at the planetary scale. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.936972
15. Dewey J. [1938]). Experience & Education. Collier Books; 1953.
16. Ellwood ER, Crimmins TM, Miller-Rushing AJ. Citizen science and conservation: Recommendations for a rapidly moving field. Biol Conserv. 2017;208:1–4.
17. Falk-Andersson J, Berkhout BW, Abate TG. Citizen science for better management: Lessons learned from three Norwegian beach litter data sets. Mar Pollut Bull. 2019;138:364–75.
18. Fox N, Marshall J, Dankel DJ. Ocean Literacy and Surfing: Understanding How Interactions in Coastal Ecosystems Inform Blue Space User's Awareness of the Ocean. Int J Environ Res Public Health. 2021;18(11):5819. https://doi.org/10.3390/ijerph18115819.
19. Gagneur A, Gagnon M. (2025). PhiloMaris: Transformer l'éco-anxiété des jeunes en éco-action en philosophant sur l'océan. *Éducation relative à l'environnement. Regards-Recherches-Réflexions*, (Volume 20.1).

20. Garcia-Soto C, Seys JJC, Zielinski O, Busch JA, Luna SI, Baez JC, Domegan C, Dubsky K, Kotynska-Zielinska I, Loubat P, Malfatti F, Mannaerts G, McHugh P, Monestiez P, van der Meeren GI, Gorsky G. (2021). Marine Citizen Science: Current State in Europe and New Technological Developments. *Frontiers in Marine Science*, *8*. https://doi.org/10.3389/fmars.2021.621472
21. Gómez S, Garriga A, Bosch MT, Bosch M, Villasante S, Salazar J. Ocean literacy in managing marine protected areas: bridging natural and cultural heritage. Front Mar Sci. 2025;12:1540163.
22. Guest G, Bunce A, Johnson L. How many interviews are enough? An experiment with data saturation and variability. Field methods. 2006;18(1):59–82.
23. Harley MD, Kinsela MA. CoastSnap: A global citizen science program to monitor changing coastlines. Cont Shelf Res. 2022;104796. https://doi.org/10.1016/j.csr.2022.104796.
24. Hays GC, Richardson AJ, Robinson C. Climate change and marine plankton. Trends Ecol Evol. 2005;20(6):337–44.
25. Hiller SE, Kitsantas A. The effect of a horseshoe crab citizen science program on middle school student science performance and STEM career motivation. School Sci Math. 2014;114(6):302–11.
26. Intergovernmental Oceanographic Commission. (2023). Report of the Intergovernmental Oceanographic Commission (IOC) on its activities (2022–2023). UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000386216
27. Jacquin J, Cheng J, Odobel C, Pandin C, Conan P, Pujo-Pay M, Ghiglione JF. Microbial ecotoxicology of marine plastic debris: a review on colonization and biodegradation by the plastisphere. Front Microbiol. 2019;10:865.
28. Kelly R, Fleming A, Pecl GT, von Gönner J, Bonn A. Citizen science and marine conservation: a global review. Philosophical Trans Royal Soc B: Biol Sci. 2020;375(1814):20190461. https://doi.org/10.1098/rstb.2019.0461.
29. Kimura AH, Kinchy A. Citizen science: Probing the virtues and contexts of participatory research. Engaging Sci Technol Soc. 2016;2:331–61.
30. King N, Horrocks C. Interviews in qualitative research. SAGE; 2010.
31. Kopke K, Black J, Dozier A. Stepping out of the ivory tower for ocean literacy. Front Mar Sci. 2019;6:60.
32. Locritani M, Merlino S, Abbate M. Assessing the citizen science approach as tool to increase awareness on the marine litter problem. Mar Pollut Bull. 2019;140:320–9.
33. Lotze HK. Combining love and knowledge to heal the ocean. Ethics Sci Environ Politics. 2020;20:33–9.
34. McKinley E, Fletcher S. Individual responsibility for the oceans? An evaluation of marine citizenship by UK marine practitioners. Ocean Coastal Manage. 2010;53(7):379–84.
35. McKinley E, Burdon D, Shellock RJ. The evolution of ocean literacy: A new framework for the United Nations Ocean Decade and beyond. Mar Pollut Bull. 2023;186:114467. https://doi.org/10.1016/j.marpolbul.2022.114467.

36. McKinley E, Garcia Rojas MI, Palacios MM, Nichols CG, Bhattacharjee A, Macreadie PI. Immersive citizen science experiences and their role in changing perceptions of coastal wetlands. People Nat. 2024;6(6):2261–82.
37. McKinley E, Fradera K. Shouting into the void: Democratising ocean literacy through integrating process literacy. Mar Policy. 2025;178:106731.
38. Mioni E. Percorsi nel Blu(Blue Paths): a long-lasting project to integrate Ocean Literacy and Marine Citizen Science into school curricula. Mediterranean Mar Sci. 2022;23(2):405–16.
39. Morgan A, Braungardt CB. (2025). Setting sail for resilience and ocean sustainability. Ocean Soc, 2.
40. Nursey-Bray M, Palmer R, Pecl G. Spot, log, map: Assessing a marine virtual citizen science program against Reed's best practice for stakeholder participation in environmental management. Ocean Coastal Manage. 2018;151:1–9.
41. O'Connor A. Sailing and social class. Taylor & Francis; 2024.
42. Pahl S, Wyles KJ, Thompson RC. Channelling passion for the ocean towards plastic pollution. Nat Hum Behav. 2017;1(10):697–9.
43. Payne DL, Marrero ME, Schoedinger SE, Halversen C. (2022). The rise and fall of the tide: ocean literacy in the United States.
44. Pörtner HO, Roberts DC, Masson-Delmotte V, Zhai P, Tignor M, Poloczanska E, Weyer NM. (2019). The ocean and cryosphere in a changing climate. IPCC special report on the ocean and cryosphere in a changing climate, 1155, 10–1017.
45. Queiruga-Dios MÁ, López-Iñesta E, Diez-Ojeda M, Sáiz-Manzanares MC, Vázquez Dorrío JB. Citizen science for scientific literacy and the attainment of sustainable development goals in formal education. Sustainability. 2020;12(10):4283.
46. Reason P. Sailing with Gregory Bateson. Seascapes: Shaped by the sea. Routledge; 2016. pp. 101–8.
47. Reiheld A, Gay PL. (2019). Coercion, consent, and participation in citizen science. arXiv preprint arXiv:1907.13061.
48. Robinson KL, Luo JY, Sponaugle S, Guigand C, Cowen RK. A tale of two crowds: public engagement in plankton classification. Front Mar Sci. 2017;4:82.
49. Rivera FC, Cababarros E, Obsina AM. (2025). *Empowering Local Stewardship: Citizen Science for the Validation of Mangrove and Seagrass Ecosystems in the Philippines* (No. OOS2025-90). Copernicus Meetings.
50. Sandahl A, Tøttrup AP. (2020). Marine citizen science: recent developments and future recommendations. Citiz Science: Theory Pract, 5(1).
51. Sauleau P, Poisson P, Ruault R. (2021). *Les sciences participatives dédiées à la mer et au littoral breton: état des lieux, recommandations et prospectives pour les universités ISblue* (Doctoral dissertation, IUEM Institut Universitaire Européen de la Mer).
52. Schaffer V, Tham A. Engaging tourists as citizen scientists in marine tourism. Tourism Rev. 2020;75(2):333–46.

53. Shellock RJ, Fullbrook L, McKinley E, Cvitanovic C, Kelly R, Martin V. The nature and use of Ocean Literacy in achieving sustainable ocean futures: A Systematic Map. Ocean Coastal Manage. 2024;257:107325.
54. Sciutteri V, Costa V, Malara D, Figurella F, Campbell I, Deery E, Consoli P. Citizen science through a recreational underwater diving project supports the collection of large-scale marine litter data: The Oceania case study. Mar Pollut Bull. 2024;200:116133.
55. Severin MI, Akpetou LK, Annasawmy P, Asuquo FE, Beckman F, Benomar M, Catarino AI. Impact of the citizen science project COLLECT on ocean literacy and well-being within a north/west African and south-east Asian context. Front Psychol. 2023;14:1130596.
56. Schnetzer, J., Fernandez-Guerra, A., Ristov, A. P., Glöckner, F. O., Kopf, A., Bietz,M. J., Kottmann, R., & Buttigieg, P. L. (2016). MyOSD 2014: Evaluating Oceanographic Measurements Contributed by Citizen Scientists in Support of Ocean Sampling Day †. *Journal of Microbiology &; Biology Education*, *17*(1), 163–171. https://doi.org/10.1128/jmbe.v17i1.1001.
57. Shemi A, Vardi A, Yarden A. Bringing marine microbiome research into the classroom is an essential step toward a climate literate society. npj Clim Action. 2026;5(1):2.
58. Somerwill L, Wehn U. How to measure the impact of citizen science on environmental attitudes, behaviour and knowledge ? A review of state-of-the-art approaches. Environ Sci Europe. 2022;34(1). https://doi.org/10.1186/s12302-022-00596-1.
59. Spellman K. Educating for resilience in the North: building a toolbox for teachers. Ecol Soc. 2014;20(1):46. http://www.ecologyandsociety.org/vol20/iss1/art46/.
60. Stoll-Kleemann S. Feasible options for behavior change toward more effective ocean literacy: a systematic review. Front Mar Sci. 2019;6:273.
61. Strasser B, Baudry J, Mahr D, Sanchez G, Tancoigne E. (2019). Citizen science? Rethinking science and public participation.
62. Tara Ocean Foundation Abreu Andre 1 Bourgois Etienne. Priorities for ocean microbiome research. Nat Microbiol. 2022;7(7):937–47. http://orcid.org/0000-0001. -8052-7117 Heard Edith 3 Rouse Brendan 3 Vamathevan Jessica 3.
63. The Plankton Manifesto - A call for Plankton-Based Solutions to address The Triple Planetary Crisis (biodiversity, climate & pollution). 2024: https://unglobalcompact.org/library/6242
64. Thiel M, Penna-Díaz MA, Luna-Jorquera G, Salas S, Sellanes J, Stotz W. Citizen Scientists and Marine Research: Volunteer Participants, Their Contributions, and Projection for the Future. Dans *Oceanography and Marine Biology*. CRC; 2014. pp. 257–314. https://doi.org/10.1201/b17143-6.
65. Tornero V, Hanke G. Chemical contaminants entering the marine environment from sea-based sources: A review with a focus on European seas. Mar Pollut Bull. 2016;112(1–2):17–38.
66. Treviño M, Urbanski K, Diamond E. Beyond formal ocean education: cultivating marine stewardship and care for the ocean through coastal access and shoreline experiences. Environ Educ Res. 2026;32(3):857–83.

67. Trumbull DJ, Bonney R, Bascom D, Cabral A. Thinking scientifically during participation in a citizen-science project. Sci Educ. 2000;84(2):265–75.
68. Tuddenham P, Schoedinger S, Cava F, Strang C. (2005). Science Content and Standards for Ocean Literacy: A Report on Ocean Literacy. 10.13140/RG.2.2.12126.84804
69. Tugend M. Reimagining ocean connections: Relationality and care in ocean literacy. The ocean incubator network learning toolkit. Cham: Springer Nature Switzerland; 2025. pp. 171–93.
70. Turcati L, Millour A, Debailly R, Fort K, Steinhausser A, Biets C, Dozières A. Citizen Science in Practice: How (not) to Fail? Citiz Science: Theory Pract. 2025;10(1):14.
71. Wehn U, Bilbao Erezkano A, Somerwill L, Linders T, Maso J, Parkinson S, Woods S. Past and present marine citizen science around the globe: A cumulative inventory of initiatives and data produced. Ambio. 2025;54(6):994–1009.
72. Whyte D. (2019). Belonging in the Ocean: Surfing, ocean power, and saltwater citizenship in Ireland. Anthropol Notebooks, 25(2).
73. Wichmann CS, Fischer D, Geiger SM, Honorato-Zimmer D, Knickmeier K, Kruse K, Thiel M. Promoting pro-environmental behavior through citizen science? A case study with Chilean schoolchildren on marine plastic pollution. Mar Policy. 2022;141:105035.

Footnotes

1. OL is closely linked to Ocean Decade Challenges 9 and 10, which focus respectively on equitable access to ocean knowledge and capacity development, and on improving understanding of the ocean's multiple values while addressing barriers to behavioral change for a more sustainable human–ocean relationship.
2. *Plankton Planet*. Available at: https://planktonplanet.org/ (accessed 11 June 2026).
3. For further information, see the blog post *"Unleashing the Potential of Citizen Science in AtlantECO: Sail for Science and Plankton Planet"* available at https://www.atlanteco.eu/post/unleashing-the-potential-of-citizen-science-in-atlanteco-sail-for-science-and-plankton-planet (accessed 11 June 2026).
4. All interview excerpts cited in this article are my own translations from French into English.
5. See Appendix for the interview guide and socio-demographic about the participants.
6. Similar challenges have been observed in the Plankton Portal project on the Zooniverse platform. Participants were initially tasked with species identification and detailed measurements, but these proved too difficult for most users. Engaging non-specialists in plankton taxonomy, particularly given their limited prior knowledge, is complex (Robinson et al. 2017).
7. Available at: Ré'Alizés: About | LinkedIn (accessed 18 August 2026)

Figures

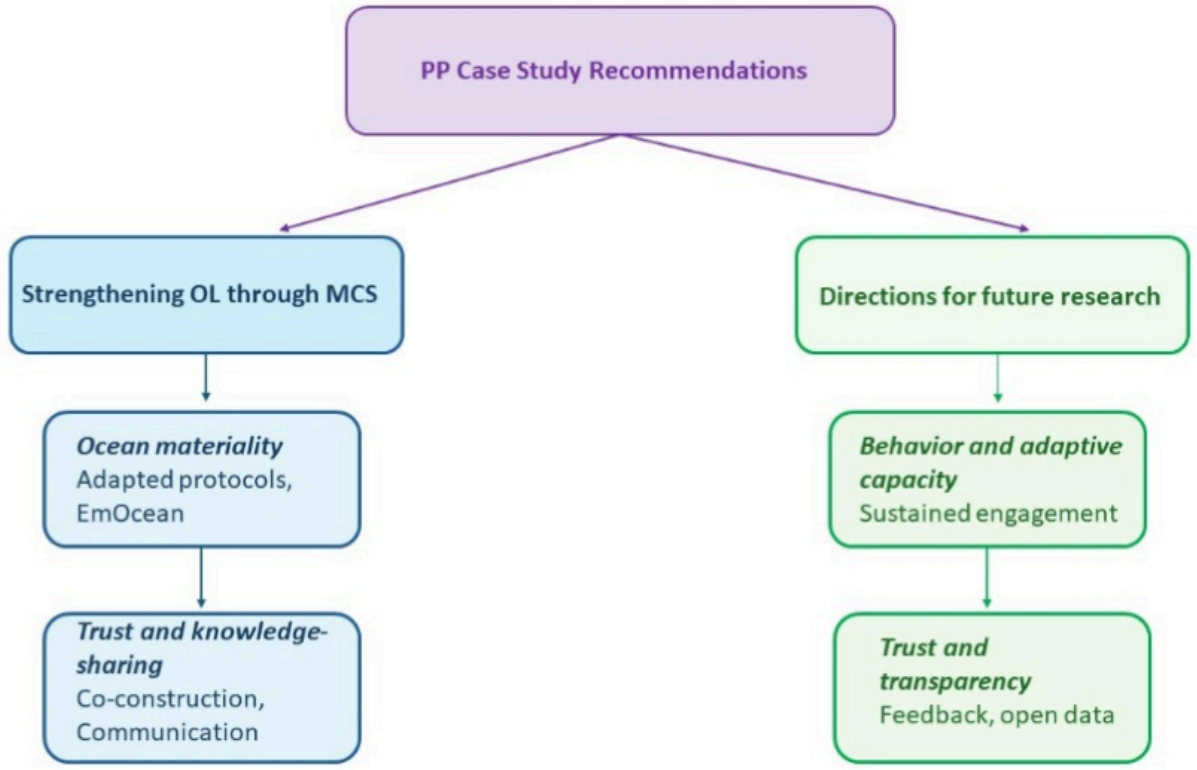


Figure 1

Recommendations for strengthening OL through MCS, derived from the analysis of PP.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix.docx