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Ocean Literacy as a Mechanism for Change Across and Beyond the UN Ocean Decade

Edited by Emma McKinley, Benedict McAteer, Berit Charlotte Kaae, and Brice Trouillet

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EDITORIAL

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Ocean Literacy as a Mechanism for Change Across and Beyond the UN Ocean Decade

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Abstract

Understanding the complexity of human–ocean relationships has been increasingly recognized as being central to addressing the triple crises currently facing the ocean and the communities that depend on it—climate change, biodiversity loss, and social inequities. Since the early 2000s, the concept of ocean literacy (OL) has evolved as a framework to explore and critically assess this relationship. Defined as having an understanding of "your influence" on the ocean and its "influence on you," OL has moved beyond its original education and knowledge roots to recognize at least 10 dimensions. These dimensions—which include themes of knowledge, emotions, attitudes and communication, and the frameworks associated with them—are increasingly being adopted, and indeed adapted, to help to further understand human–ocean relationships and to support the co-development of solutions to address ocean challenges. With the positioning of OL as a key mechanism for change within the UN Decade of Ocean Science for Sustainable Development, it is both timely and necessary to continue to examine and expand the concept of OL beyond its existing boundaries. This thematic issue demonstrates the interdisciplinarity of OL research, presenting a range of studies that critically explore how the dimensions, drivers, and impacts of OL can vary in different socio-cultural, economic, political, and geographic contexts. These studies provide crucial insight into the developing role of OL within wider ocean governance and sustainability processes. Collectively, the articles highlight the diversity of ocean literacy research emerging from the community, insights into how to further develop OL initiatives and how to maximise the potential of OL as a mechansim for change across the Ocean Decade and beyond.

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Keywords
Challenge 10; coastal communities; marine citizenship; ocean connections; ocean–human relationships; ocean identity; ocean literacy; UN Ocean Decade

1. Introduction

Although not a new concept, ocean literacy (OL) has gained significant momentum in recent years, not least as a result of its positioning as a mechanism for change within the UN Decade of Ocean Science for Sustainable Development (hereafter the UN Ocean Decade), launched in 2021. At this mid-way point of this global decadal initiative, this thematic issue is an opportunity to take stock and to build on the two decades of OL research and practice that have gone before it. Initially grounded in formal education, OL has long been defined simply as "having an understanding of your influence on the ocean and the ocean's influence on you" (Cava et al., 2005, p. 5). Early applications of OL drew heavily on the seven OL principles, largely adopting a knowledge deficit approach to fostering and improving OL. In recent years, however, researchers have proposed and explored a series of more complex models of OL (e.g., Brennan et al., 2019; Fauville et al., 2024; McKinley et al., 2023), encompassing a broader range of dimensions. While these contemporary models of OL continue to recognise the importance of ocean knowledge, communication and behaviour, they encourage a move away from the historical emphasis on knowledge within OL literature (Shellock et al., 2024) to one that is inclusive of attitudes, emoceans (McKinley et al., 2023), access and experience, adaptive capacity and more.

The growth in research effort to understand OL, and to adopt it as a lens through which the complexities of human–ocean relationships are explored, is in part driven by an increased emphasis on the role of society in addressing global ocean challenges (Bennett, 2019; McAteer & Flannery, 2022; Spalding & McKinley, 2025; Wisz et al., 2020). The UN's Ocean Decade Challenge 10 "Restoring Society's Relationship with the Ocean" (Glithero et al., 2024) explicitly highlights this, further pushing the boundaries of the original conceptualisation of OL and positioning it as more than an individual process, and as a societal outcome. These calls have been echoed throughout the ocean community through the Barcelona Statement, the Venice Declaration, and most recently through the Nice Declaration following the UN Ocean Conference in 2025.

During its more than 20-year history, OL has often found itself on the periphery of ocean sustainability discourse, a situation compounded by the concept's formal education roots. However, with a vibrant global marine social science community gaining momentum in recent years (Bennett, 2019; McAteer & Flannery, 2025; McKinley et al., 2022), the integral role of human–ocean relationships as key to delivering international and regional obligations and objectives is more evidenced than ever. Through the contributions to this thematic issue, we seek to continue to champion the expansion and critical reflection on the conceptualisation, and crucially, the application of OL. Each article engages with OL from distinct and diverse perspectives—including technological mediation, regional policy design, ocean safety, and participatory mapping—yet all converge on the need to pluralise and recontextualise the concept of OL within diverse social, cultural, and political settings. The contribution of each article is discussed in the following section, before concluding remarks are presented on how this thematic issue illustrates the growing potential of OL to function as a mechanism for change across the UN Ocean Decade and beyond.

2. OL as a Mechanism for Change

The opening article in this issue, by Portman and Portman (2025), reflects the various ways in which literature has focused on humankind's complex relationship with the sea. They explore portrayals of the sea in literary texts from three periods: the mid-19th century (pre-World War I), the mid-20th century (post-World War II), and the 21st century (current times). The article demonstrates how ocean themes are of interest in parallel with important societal shifts, tensions, and currents. It is demonstrated how popular literary works contribute to OL, both by supporting marine citizenship and by encouraging greater protection of ocean resources.

Morris-Webb et al. (2025) centre on the access dimension of OL (McKinley et al., 2023) and explore the notion of "tidal literacy" as a fundamental component of contemporary OL discourse and practice, even suggesting that its consideration is a new OL principle. Their work explores UK perceptions and knowledge relating to tides, highlighting concerningly low levels of public understanding of "tidal literacy." As research continues to push the evolution of OL, this article challenges us to ensure responsible and safe use of ocean and coastal spaces and presents recommendations as to how tidal literacy could and should be integrated into future OL initiatives.

Morgan and Braungardt (2025) focus on the potential contribution of learning theory and praxes in promoting OL. In their article, these concepts are advocated as important social dimensions of the requisite changes and outcomes required to promote the sustainability and resilience of marine environments. Additionally, the article demonstrates how to promote personal resilience and ocean stewardship as positive personal and social outcomes. These insights are exemplified through a case study of Sail Training Programmes developed and operationalised in the UK. Findings indicate the development of OL, marine identity, and marine citizenship amongst participating trainees, with key enabling factors demonstrated.

Re-considering research responsibility and knowledge dynamics in OL, Lamontagne-Cumiford and Graham (2025) assess how critical perspectives on inter-epistemic exchanges can contribute to transforming research practice. This article expands on scholarship that analyses the relationship between researchers and local/Indigenous knowledge holders, suggesting a need to move from notions of knowledge commensurability to interpersonal practices. To enable relationship-building, as a prerequisite of local perspectives and knowledge being included in research, the authors call for marine scientists to spend time disembarked from sampling vessels in local communities. In such scenarios, a paradigm shift can occur, wherein the researcher's function is that of a guest. The article demonstrates this as a process of repositioning OL as a reciprocal process.

Fidan (2025) foregrounds the epistemological dimensions of OL through an ethnographic analysis of wave buoys in the German North Sea. By examining the Directional Waverider as both a scientific instrument and a socio-material mediator, Fidan demonstrates how buoys simultaneously stabilise knowledge for coastal safety and expose the sea's inherent unpredictability. This paradox highlights the multiplicity of literacies at stake: forecast literacies generated by scientific modelling and embodied literacies cultivated through surfing and lived experiences. Drawing on Ingersoll's "seascape epistemology," the article advances a sea-centred perspective that challenges land-based assumptions and argues for recognising OL as plural and situated. Such an approach underscores the importance of embracing embodied, Indigenous, and experiential ways of knowing alongside scientific practices to foster more respectful and adaptive relations with the ocean.

Kelly et al. (2025) provide insight into the current and future role of OL in Australia. The increasing interest in OL is limited by different barriers, and the article suggests steps for progressing OL in the Australian context, including supporting ocean learning and education, engaging communities at all levels, fostering cross-sector collaboration on connecting people to the ocean, and building strong and actionable policy and funding frameworks to ensure long-term impact. It emphasizes the need to collaboratively develop a national OL strategy to guide and structure these efforts and to establish an Australian OL coalition to facilitate research, cross-sector collaboration, and implementation in practice. The overall insight into the process and visions of expanding OL in Australia is highly relevant to other countries with emerging OL communities facing similar challenges.

Critically debating the emergent field of urban marine ecology, Salazar et al. (2025) demonstrate new opportunities to promote OL and contribute to the UN Ocean Decade. The article reviews the Gorgonia Barcelona project—a collaborative and inclusive approach to fostering collaboration among a broad range of marine stakeholders—identifying learning lessons on how to co-produce knowledge on marine benthic ecosystems. The article provides a tool for exploring divers' alignment with OL dimensions. Three main diver profiles are extracted: "optimistic," "pessimistic," and "neutral." The article highlights the need for stronger conservation efforts and more sustainable, inclusive governance models in urban marine areas.

Artioli et al. (2025) add a new perspective to OL by introducing an ocean cycle-centric design approach, thereby expanding the scope of environment-centered design to the ocean realm. It defines ocean-centric design as an approach to expanding OL dimensions and driving change across disciplines by introducing and emphasizing a blue epistemology and integrating OL into resilient design practices for a restored human–ocean relation. The study proposes a framework and devises indicators to help designers ensure their practices are ocean-centric. For validation, the indicators are tested on a range of ocean-design case studies to assess whether the designs are inherently ocean cycle-centric or merely contextualized within an ocean setting.

McRuer et al. (2025) present the co-development of the Ocean and Society Survey. Adopting a transdisciplinary approach, the instrument embedded a diversity of perspectives and ensured global applicability. The survey highlights the need for dynamic, two-way engagement processes that involve people and communities in contributing to solutions and fostering a sense of shared ownership over ocean health outcomes. The development of a validated international tool for measuring OL is an important advancement that allows for understanding public ocean perceptions over time and across countries. The article highlights the role of public ocean perceptions to guide the design, facilitation, and coordination of effective engagement pathways, communication strategies, and decision-making toward measurable and solution-focused actions for the ocean.

Building on this epistemological reframing, Soffietti et al. (2025) explore OL as an operational governance tool. Focusing on the EU context, the authors examine the integration of OL within maritime spatial planning (MSP) through the development of the Regional Ocean Literacy Strategy for MSP toolbox. This methodological framework—comprising a guiding questionnaire, mapping tool, and strategy index—was co-designed and tested in Sardinia, a region with strong educational networks and institutional involvement in MSP. The findings demonstrate that OL can serve as a lever for participatory governance, policy coherence, and cross-sectoral collaboration when strategically embedded into regional planning processes.

However, the study also reveals persistent barriers, including institutional fragmentation and resource constraints, which limit long-term implementation. By presenting OL as a replicable and transferable instrument for regional governance, they position OL as a strategic asset at the science–policy–society interface.

Fauville et al. (2025) delve into the field of ocean extended reality (ocean XR), critically examining its potential to contribute to marine education and OL by simulating marine environments using augmented, mixed, and virtual reality technologies. Through an analysis of ocean XR user experiences, positive relations were identified between OL principles and key features of virtual simulations. The article represents a first step in understanding how ocean XR can benefit marine education and OL and offers suggestions for creating more impactful virtual ocean experiences.

Complementing these perspectives, Kaae and Olafsson (2025) introduce a methodological innovation for linking OL with participatory knowledge production. Using public participation geographic information systems in the Oslo Fjord, the authors collected more than 12,000 survey responses, mapping recreational activities, perceived benefits, and conflicts. The results reveal the high social value of marine recreation—particularly its health benefits—while documenting accessibility issues, environmental concerns, and user conflicts. Importantly, the participatory mapping not only generated spatially explicit data for planners but also functioned as a literacy-enhancing process: participants reflected on their relationship with the fjord, articulated problems, and proposed solutions. By integrating experiential and recreation-based knowledge with natural science data, the article illustrates how participatory methods can simultaneously enrich governance and cultivate OL, and the potential for more socially inclusive and adaptive management of coastal and marine environments.

3. Concluding Remarks

Together, these contributions exemplify the diversification and maturation of OL as both a concept and practice. Across these approaches, OL emerges as plural, situated, and deeply entangled with governance challenges and opportunities. This thematic issue thus positions OL not as a static framework but as an evolving field of inquiry and practice. By exploring a diversity of epistemological, strategic, and participatory dimensions of OL, the contributions collectively argue for embedding OL within the heart of marine governance, rather than relegating it to the margins of education and communication. Further, they underscore the potential of OL to bridge science, policy, and society; to mobilise cultural and experiential assets; and to reimagine human–ocean relationships in ways that are adaptive, inclusive, and respectful of the ocean's dynamic character. Finally, these contributions echo calls from the UN Ocean Decade Challenge 10 White Paper to reframe OL, positioning it not as an individual process or action, but as a whole society outcome. This thematic issue presents contributions that can guide, influence, and support an ongoing evolution of the concept and practice of OL that has a legacy beyond the end of the UN Ocean Decade.

Conflict of Interests

The authors declare no conflict of interests.

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ARTICLE

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Taking Ocean Literacy Literally: Reflections on Literature's Influence on Ocean Literacy

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Abstract

Throughout history, literature has focused on humankind's complex relationship with the sea. Although culture, and literature in particular, has offered readers an opportunity to learn about and connect with the ocean realm when it comes to public engagement in marine planning, which is an opportunity to take part in the allocation of ocean resources, a majority of the public is often uninvolved and unconcerned. In this article, we reflect on portrayals of the sea in literary texts from three time periods: the mid-19th century (pre-World War I), the mid-20th century (post-World War II), and the 21st century (current times). We point out how ocean themes are of interest in parallel with important societal shifts, tensions, and "currents." Further, we contend that these popular literary works, or those considered canonical, contribute to ocean literacy today, as they likely did around the time of their publication. In today's world, exposure to literature that deals with the sea could lead to greater public engagement in ocean decision-making. The ability to make decisions about ocean resources is particularly important for ecosystem-based management, which is the basis for best practices in marine planning. As with many themes dealt with in many modes of culture (music, art, theatre, etc.), literary works can contribute to marine citizenship as manifested by greater public involvement in marine planning and (perhaps) greater protection of ocean resources.

Keywords

ecosystem-based management; literature; marine spatial planning; ocean literacy; public engagement; public knowledge; public participation

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1. Introduction

The ocean is central to human health and culture. It offers many environmental benefits through ecosystem services such as atmospheric regulation and carbon sequestration, as well as through the provision of resources like food, oil, minerals, and space. These resources are a central part of life for coastal communities, where the ocean serves for recreation, fishing, and tourism. However, for today's society, ocean use often borders on exploitation and anthropogenically induced climate change threatens ocean ecosystem health (Brennan et al., 2019; Halpern et al., 2019; Stel, 2021). This is one of the reasons that marine spatial planning (MSP), "a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives" (Ehler & Douvere, 2009, p. 18), has become the main approach to allocating and managing ocean uses over the past two decades (Tissière & Trouillet, 2022).

Marine planning is a public process because the sea is considered a common pool resource in most democratic countries of the industrial world (Turnipseed, Crowder, et al., 2009). Beyond ethical and legal purposes, public consultation in planning often ensures better outcomes. Research has shown that decisions are more likely to be successful when the public is involved in general urban and regional planning (Rijal, 2023). This has certainly been true for the designation and planning of marine protected areas, which aim to protect ecosystem function, habitats for endangered species, and marine biodiversity, and are often a major use designated through MSP (National Research Council, 2001; Vaughan & Agardy, 2020).

According to Ehler and Douvere's (2009) definition, MSP underscores the need for ocean literacy (OL). Among much of the public, there is a strong disconnect between understanding what goes on in the ocean, its importance to humankind, and recognition of the need to protect marine ecosystems (Jefferson et al., 2021). Furthermore, when it comes to public engagement in marine planning, the public may be disconnected, discouraged, and distrustful of government efforts to increase participatory planning (Flannery et al., 2018; Kelly et al., 2022).

For many years, humankind's complex relationship with the sea has been reflected in Western thought and culture (Döring & Winther, 2022). In particular, the portrayal of the sea in works of literature during the past two centuries, at least among Western-world cultures, has presented to the public concepts about the ocean they would most likely not have encountered otherwise. In this article, we acknowledge the central role of oceans in literature while addressing how recognition of this role could potentially contribute to, change, or influence OL, ultimately leading to greater public engagement in the planning and management of marine resources.

2. Framing and Defining OL

The concept of OL emerged as an offshoot of environmental literacy (Payne & Marrero, 2021); both environmental and OL are offshoots of science literacy. Science literacy is defined as the ability to understand science such that it can be used to address complex science-related societal issues (Howell & Brossard, 2021). Specifically, environmental literacy aims to influence human behavior in favor of preserving the natural environment (Uyarra & Borja, 2016) and includes the "understanding, skills, and motivation to make responsible decisions that consider one's relationship to natural systems, communities, and future generations" (Molloy et al., 2021, p. 42; Figure 1).

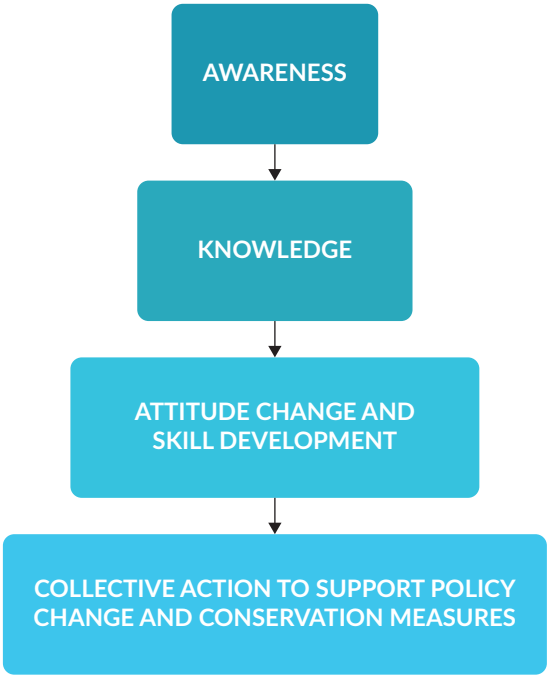

Figure 1. Flow chart depicting the result of each step in the environmental literacy process. Note: This figure is adapted from Molloy et al. (2021).

While environmental literacy was first acknowledged and defined in 1971, Brennan et al. (2019) claim that the term was only defined formally in 2004. OL has been defined as pertaining to "levels of public knowledge and informedness concerning oceans" (Steel et al., 2005, p. 97). It entails an "understanding of the importance of the ocean, the principles of how the ocean functions, and the interconnections between the ocean and people" (O'Halloran & Silver, 2022, p. 2). Further, an ocean-literate individual who possesses knowledge about the ocean uses this knowledge to make independent and important decisions about the ocean and its resources and can meaningfully communicate about these topics (Kopke et al., 2019; Schoedinger et al., 2010).

As knowledge of the ocean becomes more common and is depicted in accessible media and information sources, the general understanding of the value of our oceans, the functions oceans provide, and what constitutes healthy marine ecosystems improves. Studies have shown that OL is influenced by personal experiences, education level, age, gender, residency (urban vs. rural), and use of TV, internet, and radio (Steel et al., 2005; Steel & Weber, 2001). However, there is limited published research on the influence of literature (i.e., literary works including fiction, non-fiction, poetry, prose, etc.) on knowledge and familiarity with the ocean and its ecological importance.

A recent historical overview of the development of OL analyzes how it has led to more ocean-related research, especially across institutions and disciplines. However, while pointing out that the "scientific community" needs more exposure to OL (Paredes-Coral et al., 2021), the authors failed to examine the effect that exposure could have on the public at large, including those not engaged in marine education, science, or research. Similarly, Fernández Otero et al. (2019) highlight the importance of OL among maritime industry stakeholders, including present and future maritime workers. In general, however, the ocean lacks relevance to many people's everyday lives, leaving much of the public to conclude that the oceans are of little concern to them personally (Kelly et al., 2022).

Today, an important development is the extent to which ocean-related issues impact us in everyday life. One of the reasons this development is important is that an ocean-literate public is needed for marine planning. MSP is becoming more common among nation-states, regions, and even local jurisdictional entities—as evidenced by Directive 2014/89/EU (2014) of the European Parliament establishing a framework for MSP. In the US, Obama's Executive Order 13,547 (The White House, 2010) called for further development of coastal and marine spatial plans. Frazão Santos et al. (2014) predict that by 2030, half of the world's marine waters under national jurisdiction (i.e., exclusive economic zones according to the UN Convention of the Law of the Sea; Zacharias & Ardron, 2020) will be governed by marine plans. One of the first of these plans was already completed in 2009 (the Massachusetts Oceans Management Plan; Massachusetts Office of Coastal Zone Management, n.d.). The main outcome of these plans is the allocation of ocean resources—including space—for human activities. As the ocean and shores are common goods, the public should be involved in this allocation process. As mentioned, Ehler and Douvere's (2009) handbook on MSP defines it as a "public process." Thus, for better planning, for questions of equity and justice, and for true public processes to occur, an ocean-literate public is needed.

3. OL Timeline

In a 2016 article, Uyarra and Borja cite the first and only article on "marine literacy," the initial concept that laid the foundation for "OL," published in 1980 by Barbara Spector. This article summarizes efforts to "develop a nation of marine literate citizens" in order to improve public funding for marine-policy-related projects and the conservation of marine resources (Spector, 1980, p. 31). Spector (1980, p. 31) defines marine education as "general learning intended to impart marine literacy, so all citizens become aware of the potential for wise use of the marine…environment in their daily lives." She emphasizes the importance of marine education both through formal courses at every age and through community programs. Specifically, she suggests that educators focus on incorporating marine matters into curricula, with the goal of educating students, parents, and their communities (Spector, 1980). The tying of literacy to institutionalized education contributed to subsequent definitions of OL.

Since the early 2000s, OL has developed and progressed. The Ocean Project's (1999, p. 1) survey of 1,500 adults explored "the public's connections, values, attitudes, and knowledge relating to the oceans." Survey results suggested that Americans have "superficial" knowledge of the ocean. While acknowledging that oceans must be protected for humans to survive, for the most part, individuals do not understand how oceans benefit humans or how humans negatively impact ocean health (The Ocean Project, 1999). Subsequently, the Pew Oceans Commission (2003, p. 91) identified a need for "a new era of ocean literacy that links people to the marine environment." This followed the release of numerous studies indicating the serious decline of environmental conditions of oceans and coasts (McKinley et al., 2023; Steel et al., 2005).

In 2009, June 8th was established as the "World Oceans Day" for citizen science, ocean awareness, and educational activities (Stel, 2021). In 2010, educators and scientists established a definition of the ocean-literate individual characterized by an understanding of the ocean, responsible decision-making skills, and communication abilities (see Figure 2, second row) regarding ocean use and resources (Kopke et al., 2019). Similarly, the connection between society, culture, and oceans is acknowledged by the declaration of the UN Ocean Decade and Agenda 2030's sustainable development goals (SDGs), including "life below water" (SDG 14). These global initiatives require strong societal involvement to change humans' relation to

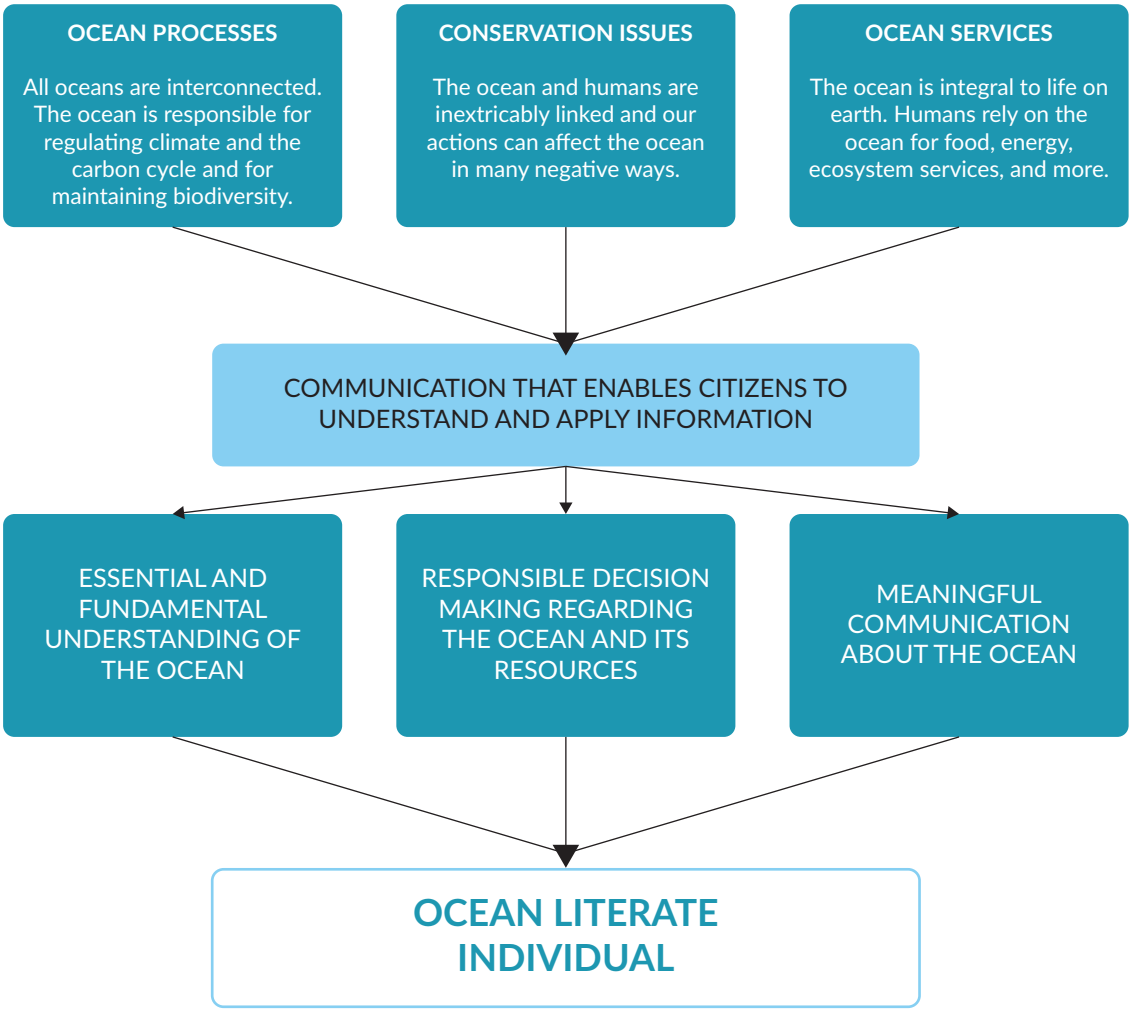

Figure 2. The OL development framework. Notes: This figure is adapted from Kopke et al. (2019); the top three boxes cover OL themes and the lower boxes describe what makes an individual ocean literate.

the ocean, for which literature could play an important role (Mentz, 2024; Omstedt, 2023; Omstedt & Gustavsson, 2022).

As the concept of literacy has been applied to new fields (e.g., education and planning), OL activities have broadened and expanded. Whereas the original definition of OL included knowledge, awareness, attitude, behavior, activism, and communication as basic goals (Brennan et al., 2019), recent framings of it propose adding emotional connections (emotional reaction to ocean-related issues), access and experience (physical or virtual accessibility to the ocean), adaptive capacity (capability to act in response to changing ocean conditions), and trust and transparency of information sources (McKinley et al., 2023).

While first developed for formal educational purposes focused on teaching OL in a one-way flow of information (UNESCO, n.d.), OL has more recently broadened to include action and engagement-based educational models that emphasize appealing to social norms and emotions, with the goal of inspiring changes in behavior and action (McKinley et al., 2023). Achievement of these goals could significantly improve public participation in ocean policy decisions and interest in sustainability.

4. OL and Public Engagement

OL allows individuals to influence and participate in public policy decisions about oceans (Steel et al., 2005) and can encourage and support citizen science data collection (Portman, 2016). OL can also "create societies that understand their interconnected relationship to the ocean, enhancing their ability to make informed and responsible decisions about marine resources" (Kopke et al., 2019, p. 2), and thus encourage stakeholders and the public to manage ocean resources and marine ecosystems sustainably.

Collective action informed by OL is necessary for both marine development and conservation. This idea holds for several reasons. Primarily, throughout the ages, resources of the sea—like other natural resources (e.g., air and navigable rivers), and particularly biogenic resources (e.g., wood, manure, and crude oil)—have been held in public trust. The public trust doctrine, incorporated by many regulatory systems, has roots in the English common law and before that in Roman law (Blumm & Wood, 2021). The doctrine is a powerful legal concept that obligates governments to manage natural resources, including the shores and the seas, for the benefit of their citizens (Turnipseed, Roady, et al., 2009). Therefore, it is essential that the public understand, communicate, and know about the sea.

5. OL Through Literature

Here, we examine societal connections to the ocean found in literary works of three eras. The books we chose to analyze represent widely read current literature or literary works canonized over the years since their publication inspired interest in and connection to the ocean among their readers. We contend that these popular literary works contribute to OL today, as they likely did—albeit to varying extents—around the time of their publication. This idea is linked to engagement-based models of education, particularly those related to emotional reactions and personal experience with ocean subjects as mentioned by McKinley et al. (2023) within the framework of OL.

We start with two works of literature from the mid-19th century, then highlight two exemplars from the mid-20th century, and culminate with two current books. For the most part, the literature we address in the first era (the mid-19th century) has relevance today due to its canonization over time. Melville's *Moby Dick*, which was not widely popular when first published, has become somewhat of a quintessential text as evidenced by the seemingly unending references to the work and its myriad messages, themes, and complexity (e.g., Edwards, 2006). In each of the three periods, the themes mentioned and identified in the literature we choose involve cultural concerns of the time, developed or evolving values, and distinct societal themes. While these literary works were popular or became so over the years since their publication, they also highlighted important major societal themes of their time (see Table 1). Today, as in the past, their authors expose readers to these themes, while also edifying about new horizons, primarily the unknown and unfamiliar ocean environment.

First, we consider Herman Melville's *Moby Dick* and Jules Verne's *Twenty Thousand Leagues Under the Sea*. Then we look at Rachel Carson's books on the marine environment as well as Ernest Hemingway's *The Old Man and the Sea*, both from the post-World War II era. In the contemporary era, we examine Wallace J. Nichols' *Blue Mind* and Lulu Miller's *Why Fish Don't Exist*. The impact of such works, both fiction and non-fiction, on readers, can be understood in relation to accepted societal norms and how the ocean is understood vis-à-vis society and the individual.

5.1. Period I: Mid-19th Century

Melville's *Moby Dick* (1851) brings, among others, the themes of (a) fear of the unknown and (b) man's struggle for dominance over nature juxtaposed with reverence towards it. The first theme is evoked as the whale itself symbolizes the sublime and unknowable, exemplified by Melville's description of "the unearthly conceit that Moby Dick was ubiquitous; that he had actually been encountered in opposite latitudes at…the same instant of time" (Melville, 1851, p. 148). This perception is indicative of the conception held at the time of the novel's publication (and in some circles today) of the ocean as limitless, signified by the omnipresence of the main character, the great white whale.

Melville's text also portrays the workings of the American whaling industry, which signifies man's intention to dominate nature. In this theme, the whale symbolizes the uncontrollable force of nature. Captain Ahab describes the whale as "that inscrutable thing…chiefly what I hate; and be the white whale agent, or be the white whale principal, I will wreak that hate upon him" (Melville, 1851, p. 131). This sentiment denotes the belief that humans existed against nature as a separate entity, a foreign one, and a force to be reckoned with. Still, the conclusion of the story invalidates this thinking—instead of accomplishing the goal of capturing the whale and thus defeating this opponent, "all collapsed, and the great shroud of the sea rolled on as it rolled five thousand years ago" (Melville, 1851, p. 459).

But some see in the conflict between the whaler (Ahab) and the whale (Moby Dick) the need for reverence of—and even compassion for—nature. In his essay, *Eight Ways of Looking at Samuel Beckett*, Nobel laureate in literature J. M. Coetzee contends that many things are missing from previous Nobel laureate Beckett's account of life, of which "the biggest is the whale" (Coetzee, 2018, p. 205). In explaining his view of Beckett, Coetzee quotes Melville's novel:

> "Captain Ahab, I have heard of Moby Dick," says Starbuck, the mate of the Pequod. "Was [it] not Moby Dick that took off thy leg?" Ahab answers, "Aye…it was…For that I'll chase that white whale…over all sides of the earth, till he spouts black blood and rolls fin out." But Starbuck is dubious and answers him "…vengeance on a dumb brute…that simply smote thee from blindest instinct. To be enraged with a dumb thing, Captain Ahab, seems blasphemous." (Melville, 1851, p. 80)

These aspects of the story echo the cultural themes of the time. A major event around this time was the emergence of two main schools of thought representing opposing attitudes toward the natural environment. During the mid-19th century, the tensions between John Muir's (1838–1914) preservationist movement and Gifford Pinchot's (1865–1946) conservationist movement were starting to gain momentum. The ideas that each advocated centered around whether humans should revere nature for its inherent value or manage it for exploitation. The latter idea rests on the domination of nature and its use, as needed, for humans (Caulfield, 1989).

In Jules Verne's *Twenty Thousand Leagues Under the Sea* (1869), we recognize themes of technological advancement and global cooperation. When the self-sufficient submarine powered by sea minerals emerges, the theme of technological advancement comes to light, especially as the suspicion that the creature is a submarine is initially dismissed; it was not technologically feasible at the time the novel was written. The awe with which the public in the story conceptualizes the submarine and its impressive construction also plays into this theme.

The theme of global cooperation comes to light with the discovery of the ship, which would not have been possible without the collaboration of experts from different countries, indicated by the mention of "the nations united against" Captain Nemo (Verne, 1869, p. 361). These themes represent developments in society at the time, including the rapid advancements of the Industrial Revolution and the beginning of worldwide international cooperation, eventually leading to the birth of the League of Nations following World War I (UN, n.d.). New technological advancements during this time, like the telegraph, steam engines, and railroads, allowed for the ease of communication and transport between the countries, which is highlighted in Verne's tale.

5.2. Period II: Mid-20th Century (Post-World War II)

Rachel Carson is most famous for her 1962 book, *Silent Spring*, which is considered one of the founding texts of the modern-age environmental movement. Three earlier works, *Under the Sea Wind* (1941), *The Sea Around Us* (1951), and *The Edge of the Sea* (1955), were also ground-breaking *New York Times* best-sellers, with the second staying atop the bestseller list for 39 weeks (Souder, 2012). All three explored sea and shore life. Specifically, we highlight two of Carson's themes from these publications: (a) Humans have a significant, often nefarious, impact on the environment, and (b) man is undeniably subordinate to and cannot fully know the sea.

The first theme emphasizes how humans impact the marine environment and calls for responsible stewardship and advocacy:

> The tragedy of the oceanic islands lies in the uniqueness, the irreplaceability of the species they have developed by the slow processes of the ages. In a reasonable world men would have treated these islands as precious possessions, as natural museums filled with beautiful and curious works of creation, valuable beyond price because nowhere in the world are they duplicated. (Carson, 1951, p. 95)

Here, Carson pays special attention to the changing climate, ostensibly being one of the first popular authors to address the concept (Blum, 2017). While she does not seem to recognize just how problematic the warming climate is, she does emphasize man's improper use of ocean resources. This displays a post-World War II shift from the previous era's themes of fear and uncertainty of the ocean, with inklings of the need to treat marine life with respect, perhaps echoing even Melville (see Starbuck's reaction to Captain Ahab's obsession with the whale in Section 5.1) and moving on to the outright novel idea of the need to preserve it.

Regarding the second theme, although efforts to apply new technologies to deep sea exploration at the time of these era's publications were numerous, the sea was (and still is) largely unknown and undiscovered. Carson notes that even revered ocean explorers were wrong about many of their observations. These ideas paved the way for conflicting views oscillating between acceptance of the urgent need for ocean stewardship and the view of the ocean as a provider of new resources for the technological age.

Like the two themes in Carson's works, Ernest Hemingway's *The Old Man and the Sea* (1952) highlights, on one hand, human reverence of nature and, on the other, man's struggle with it. This dichotomy is exemplified in the quote:

> You are killing me, fish, the old man thought. But you have a right to. Never have I seen a greater, or more beautiful, or a calmer or more noble thing than you, brother. Come on and kill me. I do not care who kills who. (Hemingway, 1952, p. 41)

The theme of respect for the ocean in Hemingway's novel is especially strong and consistent with the idea of stewardship mentioned above in the discussion of Carson's books. The juxtaposition of these opposing relationships between man and nature (e.g., the urge to "kill" the fish while also calling it "noble") is indicative of this era's transition from a feeling of trepidation towards the ocean to one of admiration. This highlights the conflict between stewardship and the provision of an important, exploitable resource, similar to what we mentioned in Section 5.1 concerning *Moby Dick*. Interestingly, assuaging these conflicts is an important goal of MSP (Ehler & Douvere, 2009, p. 57; Portman, 2016).

5.3. Period III: The Modern Age (21st Century)

Wallace J. Nichols' *Blue Mind* (2015) emphasizes individualism, a theme that is prominent in today's (Western-industrialized) society. Nichols claims, "water quiets all the noise, all the distractions, and connects you to your own thoughts" (Nichols, 2015, p. 267) and "when we tell stories of our own interactions with water we turn 'water' into a personal, individual experience" (Nichols, 2015, p. 260). He details many examples proving that interacting with the ocean improves mental and physical health. For example, he quotes a study that suggests that individuals in "coastal communities may attain better physical health due to the stress-reducing value of greater leisure time spent near the sea" (Nichols, 2015, p. 162).

In modern society, individualism, or "individualization," is a sociological idea that emphasizes the tendency of "individuals [to] increasingly become 'self-referential,'" focusing on the power of individual choices rather than coming together for purposes of collective action (Rasborg, 2017, p. 230). Nichols' central argument that interacting with water awakens and empowers the individual is followed by a warning against humans maintaining an "egocentric" relationship with nature, i.e., "see[ing] nature strictly from the perspective of what it can do for me personally" (Nichols, 2015, p. 250).

Further, Nichols balances the focus on the individual with a second theme of connectivity through water. "We are connected to each other, emotionally and biologically," he writes. "[Each blue marble, a physical representation of our planet] symbolizes the deep connection between people and this planet" (Nichols, 2015, pp. 274–275). In addition to balancing the first theme, the concept of connectivity counters the social phenomenon of aloneness. Early recognition of the current era's pervasive "aloneness" is emphasized in Robert Putnam's seminal work, *Bowling Alone* (2000). Putnam describes a distancing of Americans from community and social involvement and calls for a reorientation of American culture to a socially focused one. This includes recognition of "social capital" and a return to the benefits of connection with peers and unity with people from other backgrounds. The renewed connection with others that Nichols describes—a bond formed by interacting with water—can lead to greater connections at the individual and community levels. Nichols quotes Carl Sagan on this point: "[the pale blue dot of our planet] underscores our responsibility to deal more kindly with one another and to preserve and cherish the…only home we've ever known" (Nichols, 2015, p. 275).

In Lulu Miller's *Why Fish Don't Exist* (2019), like *Blue Mind*, we encounter themes of individuality, however, in the former, this theme appears with the theme of complexity. Miller retells scientist David Starr Jordan's life story in parallel to her own challenges in determining her own individual identity. Jordan (1851–1931), an ichthyologist by training, rose to fame due to his identifying and naming over 2,500 fish species. Individualism and complexity merge as Miller seeks to understand ponderings of the individual: "How lonely it can feel inside a head with ideas you can't figure out how to spit out" (Miller, 2019, p. 90). In describing the research challenges faced by Jordan, Miller notes in an interview with National Public Radio, "In anything we do we are looking for these proxies to parse the chaos" (Shapiro, 2020, para. 9). About science, she writes, "the work of good science is to try to peer beyond the 'convenient' lines we draw over nature…[and] know that in every organism at which you gaze, there is complexity you will never comprehend" (Miller, 2019, p. 162). These themes are consistent with contemporary concepts of breaking unexpected boundaries, navigating intricate political and social issues, and individualistic tendencies.

In addition to exploring themes of complexity parallel to coming to accept her own ambiguous sexual orientation, Miller reinforces new discoveries about marine wildlife. Despite the issues she has with Jordan's person, she recognizes him as "the swashbuckling giant of fish discovery" (Miller, 2019, p. 170). Still, her main point—and the reason for the alluring title *Why Fish Don't Exist*—is that the categorization of "fish" is merely a result of the human obsession with making things neat and tidy, with denying that life is inherently complex. But, alas, she concludes it is utterly meaningless. In fact, "many of the fishy-looking creatures swimming in the water are more closely related to mammals than to each other….'Fish' as a sound evolutionary category is totally bunk….Fish don't exist" (Miller, 2019, pp. 171–175).

As mentioned, throughout the book, Miller struggles to understand her own sexual orientation; for a time, she believed that she must be placed into a neat category. But, like fish, the category was meaningless and her own identity was far more complex. "A category," Miller writes, "is at best a proxy; at worst, a shackle" (Miller, 2019, p. 193). With her book, Miller ultimately makes a statement about chaos and the rejection of traditional categorization, which she reveals through the lens of Jordan's impressive feats in the world of fish identification, a major step in ocean discovery. Although Jordan was obsessed with taxonomy and overcame many setbacks in his attempts to name all fish, much of his work is invalid because fish never existed to begin with!

Table 1. Summary of the relevant themes found in the selected literature.

Period	Book	Theme 1	Theme 2
Period I: Mid-19th century	*Moby Dick* (1851)	Fear of the unknown	Man's dominance over nature
	Twenty Thousand Leagues Under the Sea (1869)	Technological advancements	Global cooperation
Period II: Mid-20th century (post-World War II)	*The Sea Around Us* (1951) *The Edge of the Sea* (1955)	Man cannot know the sea, despite what he may believe	Man's impact on the ocean/environment
	The Old Man and The Sea (1952)	Man's respect for nature	Man's struggle against nature
Period III: The Modern Age (21st century)	*Blue Mind* (2015)	Individualism	Connectivity
	Why Fish Don't Exist (2019)	Respect for individualism	Categorization challenged by complexity

6. Discussion

Exposure to literary works in popular culture has always impacted society's interest and understanding of the sea. Literature brings important lessons, facts, and general knowledge of the sea while appealing to large audiences of readers, listeners, and even viewers. This is especially true as literary works, even those of the distant past, are adapted for different media, particularly film. An example is *The Perfect Storm* by Sebastian Junger (1997), a non-fiction, journalistic account of the challenges faced by fisherfolk and their communities off the coast of New England, adapted for film in 2000.

With MSP becoming more prominent (Frazão Santos et al., 2019), increasing people's experiences with the ocean can encourage care of the marine environment, especially if they understand that what is described is threatened. Beyond learning about marine uses and the ocean's importance for providing ecosystem services to humans, readers of popular literature can better understand the purpose and need for healthy marine ecosystems.

While more research should be done on how to best take advantage of how literature has and will influence OL, we see three major implications. First, OL campaigns should consider reaching the public through all types of media, with a focus on not only teaching marine science but also fostering more general connections to the marine environment through culture and art. Second, arts and humanities should be incorporated into marine education materials and curricula. Third, more research is needed on how popular literature can teach, expose, and lead to a better understanding of the importance of the marine environment and its relevance to everyday life. The above points have been recognized by other scholars (e.g., *Introduction to Blue Humanities*; Mentz, 2024). Humanities, social sciences, life and natural sciences all have a role to play in the planning of marine space. The different disciplines that are currently called to come together, as in paradigms such as integrative marine planning and integrated coastal management, have in the past been siloed (Portman, 2016).

The implications resulting from this research should be considered along with the limitations of our study. We used neither the usual methods of literary study nor those typical of social science research. In the future, more systematic, rigorous methods could be applied to this topic for more comprehensive results. Also of note is that the works analyzed in this study represent mainstream imaginative engagement produced within and for a western-global north readership (e.g., Edwards, 2006). In the future, readership of other cultures and geographic regions should also be addressed.

Despite the limitations of our methods, they were effective for our exploratory research (Bhattacherjee, 2012). We choose important texts and their periods randomly as the "backdrop" of the social phenomenon of engagement in the political process and of space allocation in the marine environment. This selection approach was appropriate for this type of exploration and reflection. Our approach is neither an exhaustive review of literary criticisms, an analysis of literary studies, nor representative of all time periods since the mid-19th century. Rather, this study is among the first attempts to integrate typical marine social science topics, such as those frequently addressed in academic journals like *Marine Policy* and *Ocean and Coastal Management*, with those of the humanities. An important current topic of debate and discussion is how to achieve ecosystem-based management (EBM) through marine planning (Domínguez-Tejo et al., 2016; Jones et al., 2016; Trouillet & Jay, 2021) and to this discussion, we hope to have contributed.

7. The Importance of Healthy Marine Ecosystems

The ecosystem-based approach is invariably relied on as a foundation of MSP (Directive 2014/89/EU, 2014). The application of this approach is anchored in the EU's Integrated Maritime Policy, which depends on EBM to achieve "sustainable development of seas and oceans" (Directive 2008/56/EC, 2008). Defined as "an integrated approach to management that considers the entire ecosystem, including humans" (McLeod et al., 2005, p. 1; Portman, 2016), EBM focuses on managing human activities that impact the ocean and coastal environment in a way that maintains the health and resilience of the ecosystem and the services it provides (Directive 2014/89/EU, 2014; Ehler & Douvere, 2009; Frazão Santos et al., 2014; Mengerink et al., 2009).

This concept of ecosystem health is paramount to successful MSP, a process that requires the engagement of "multiple actors and stakeholders at various governmental and societal levels" (Olsen et al., 2014, p. 1), especially due to the "public" nature of the sea (Chalastani et al., 2021; Frazão Santos et al., 2019). Furthermore, many marine scientists decry the tension between EBM (or environmentally sustainable planning) and blue growth (Frazão Santos et al., 2014; Leslie & McLeod, 2007; Zuercher et al., 2022), defined as "smart, sustainable and inclusive economic and employment growth from the oceans, seas and coasts" (Sekimizu, 2012, para. 8) as both are promoted in marine plans (Jones et al., 2016). There is increasing emphasis on the expansion of maritime sectors of the economy with blue growth. At the same time, EBM is called for as the foundation of marine planning efforts (see previous paragraph).

Public engagement in terrestrial planning involves the allocation of space in cities, communities, and even large tracts of open space (such as national parks and agricultural lands) almost always geographically near to those engaged. In addition to the physical distances between marine environments and the public, issues of ownership and belonging in the marine realm are usually vague (Agardy, 2000). Scholars on MSP have found that the geographic scale and location of members of the public can be a determinant of engagement in a marine planning process; those living in coastal communities may be more likely to participate than those living inland (Tissière & Trouillet, 2022; Zaucha & Kreiner, 2021).

In a comparative study of 16 marine spatial plans, Collie et al. (2013) found that although stakeholders' roles were generally clearly defined in these plans, they did not participate in all stages of the planning process. A more recent study found that "in Europe and probably beyond, the future of the MSP system is still largely linked to its capacity to foster forms of participation that would not be mere procedural artefacts" (Tissière & Trouillet, 2022, p. 28). While research is needed on why participation in marine planning often wanes (Zaucha & Kreiner, 2021), distance, unfamiliarity, and lack of knowledge about how the sea affects civil society could be factors.

As mentioned, marine space is one of the most salient types of public domain (Leslie & McLeod, 2007; Portman, 2006; Turnipseed, Roady, et al., 2009), often referred to as the "ocean commons" (Braverman, 2022). Therefore, research is needed focusing on the management of human uses of the sea according to the EBM approach using public sector planning paradigms. One of these planning paradigms is collaborative planning, which, like participatory planning used in EBM, emphasizes the participation of stakeholders and the general public. For example, research on how participants from indigenous societies might lead to better marine planning outcomes is needed (Tissière & Trouillet, 2022; Vierros et al., 2020). Marine spatial plans that incorporate

important principles of planning theory related to the planning of public commons will likely be better at successfully implementing meaningful EBM.

Here we contend that the combined influence of structured OL efforts (such as those mentioned in Boaventura et al., 2021; Brennan et al., 2019; and Guest et al., 2015) and literary works that deal with the sea and all its complexities can encourage a broad range of stakeholders to engage in marine planning. Literary scholars and marine activists, planners, and oceanographers may be coming together as evidenced by current and relatively new studies such as Mentz (2024) and Omstedt and Gustavsson (2022). More specifically, marine planning programs should consider the contributions of the arts and humanities to marine social science and marine education. Literature portrays the ocean in creative, interesting, and culturally relevant ways. Literature may be unique in its ability to educate readers, broaden horizons, and draw in readers through plot, narrative, and subtle messaging. It has contributed and continues to contribute to OL.

Due to the widespread exposure of the populace to the literature we mention, increased knowledge of and appreciation for the sea is achieved even by works having other non-marine-related messages for society. The societal themes communicated in them could bring people figuratively closer to the ocean and increase their concern with it. Lastly, since we are terrestrial beings and the threats to our oceans are so great, every opportunity to inculcate various aspects of the marine environment should be recognized and encouraged. Such connections could lead to caring for the marine environment, improve public engagement in what goes on in the sea, and expand links between oceans and society.

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Conflict of Interests

The authors declare no conflict of interests.

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ARTICLE

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Making the Sea Knowable: Ocean Literacies From a Sea-Centred Perspective

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Abstract

In this article, I focus on the wave buoy and how it expands the concept of ocean literacy. The Directional Waverider buoy, manufactured by Datawell, is used worldwide to measure waves to produce knowledge about oceans in the context of rising sea levels and storm surges. My ethnographic fieldwork took place on the German North Sea coast, where these ocean developments affect the low-lying coastline. Using buoys along the coast is one way of making the sea knowable through datafication and climate modelling. To understand how the buoy pushes the limits of the concept of ocean literacy and what this means for human–ocean relations, I focus on the knowledge production processes of scientists working with the buoy and its data, and how the established infrastructure territorialises the North Sea. I subsequently show how the wave buoy rides the waves and how this relates to my embodied knowledge of the sea, drawing on Ingersoll's concept of "seascape epistemology." I argue that these knowledge practices are based on a sea-centred perspective, and that in order to remain stable, this infrastructure needs to be as supple as the sea. I conclude by suggesting that it is important to understand ocean literacy as a plural concept, as ocean literacies, as demonstrated by these plural knowledges.

Keywords

climate change; datafication; embodied knowledge; knowledge production; maritime anthropology; ocean literacies; seascape epistemology; territorialisation

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1. Introduction

The concept of ocean literacy aims to better understand human–ocean relationships (McKinley et al., 2023). It is mainly developed from a land-centred perspective, targeting people's behaviour towards the ocean. The concept emphasises different aspects of the management and governance of the ocean—of making it legible. Knowledge of the ocean is one of these aspects. In the context of climate change and my field case, knowledge of the sea is needed to help protect people from rising sea levels and storm surges by building and elevating dykes and other elements of infrastructure that are used to manage and govern the ocean. To produce this knowledge, wave buoys, among other things, are deployed worldwide to record the behaviour of waves along the coasts. This brings us to the central figure of my ethnographic work: the wave buoy (see Figure 1). In this article, I examine, from an ethnographic perspective inspired by science and technology studies (STS), how the wave buoy measures waves and contributes to the datafication, territorialisation, and management of the ocean. My work thus contributes to the field of maritime anthropology, which focuses on human–ocean relationships (Roszko, 2021). Roszko (2021) notes that, despite a focus on the ocean, anthropological research has for a long time been situated in a land-centred perspective. This article challenges this terrestrial bias by turning attention to how the buoy rides the waves and reflecting on what this means for how the sea is shaped in knowledge production. In addition, this perspective allows me to challenge the land-centred perspective that often underlies the concept of ocean literacy. I aim to show that there are plural ways of being ocean literate and how these ways can be more sea-centred.

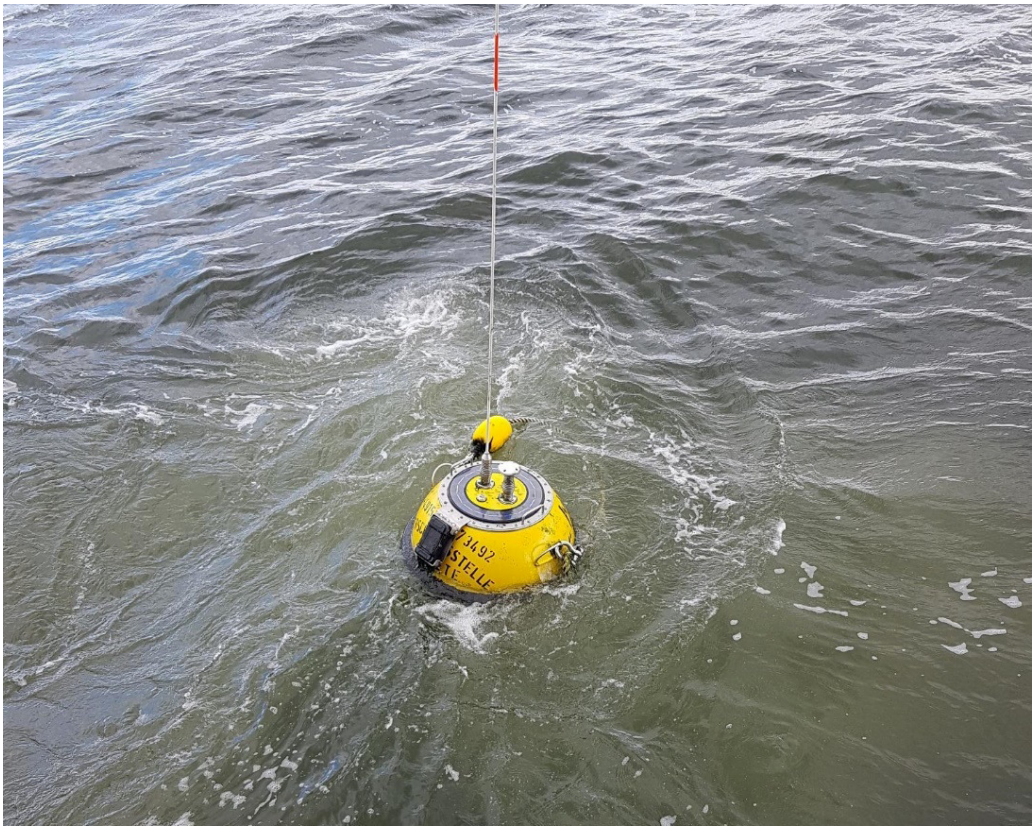

Figure 1. Wave buoy in the North Sea.

My interest in the wave buoy emerges from my experience surfing. From the beginning, I had noticed something of an obsession that surfers had with the surf forecast, which plays a major role in every conversation between them. After a few years of surfing, I wondered how the surf forecast, which I would use every day for surfing, is made. The answer from a friend was: with buoys that measure waves off the coast. My ethnographic curiosity was aroused. After some research, I soon found out that one of the most widely used wave buoys is the Directional Waverider from the Dutch company Datawell. It was developed following a severe storm surge in the Netherlands in 1953 to monitor the behaviour of waves a few kilometres off the coast. The aim was to prevent such serious disasters in the future (Joosten, 2013). Until today, knowledge about the waves is produced through these wave buoys to help ascertain the strength of the dyke infrastructure along the North Sea coast as well as to make better predictions about when and how strong the next storm surge will be. To predict storm surges, and create surf forecasts, climate models are used. Based on model data and observational data, they calculate how and when the next storm surge can be expected. The vision of ocean management is now so far-reaching that efforts are being made to develop a digital image of the Earth, or what is called a digital twin. The digital twin can be understood as an Earth system model in which all climate models that have had different orientations are combined into one. The digital twin is intended to provide an even more comprehensive overview of planetary developments and make them manageable (field note, October 5, 2023; Rothe, 2024). This project requires data from wave buoys.

As part of this research, I worked with scientists from three scientific and state institutions that work with the wave buoy or the data it generates on the German North Sea coast. These scientists maintain the buoys, look after the measurement network, and use the data from the wave buoys to research waves, storm surges, and storms—and thus produce knowledge about how waves behave. I see this knowledge production as one form of ocean literacy. The design and operation of the buoy and the knowledge practices around it play a crucial role in building infrastructures and therefore influence how people living on the German North Sea coast shape their relationship with the ocean. In this article, I will argue that there are other ways of understanding ocean literacy. Both the ways in which the buoy rides the waves, and my embodied surfing knowledge point to a plural understanding of ocean literacy. To argue this, I will draw on Ingersoll's concept of "seascape epistemology" (2016), which brings in an Indigenous perspective of being and moving with the sea in constant movement. In other words, I am interested in how the wave buoy expands the concept of ocean literacy, and in what it can teach us about human–ocean relationships.

To analyse this, I will begin by describing in the next section how the scientific practices and the wave buoy are connected and how the buoy acts as a mediator. The third section then focuses on how the infrastructure around the buoy territorialises the North Sea from a land-centred perspective. In the fourth section, I describe how by riding the waves the wave buoy is in excess of them and how this is connected to embodied surfing practices in order to argue that ocean infrastructure has to be as supple as the sea itself. Finally, I draw on Ingersoll's concept of "seascape epistemology" (2016) to develop a sea-centred perspective that acknowledges plural knowledges of the sea to then argue for a plural understanding of the concept of ocean literacy—ocean literacies.

2. The Wave Buoy as a Mediator: Scientific Practices

The wave buoy is yellow, waist-high, heavy, made of stainless steel, and reminds me of the Minions from the film *Despicable Me*. With a built-in accelerometer it can measure the wave spectrum, e.g., wave height and

wave direction (Helmreich, 2019; Nielsen et al., 2023). It is deployed in the ocean near the coast, is regularly maintained, and sends data every half hour through a radio signal at a particular frequency to its receiver, which is often located on land or, if at sea, on offshore facilities. These data are then further processed by different kinds of scientists. I worked with meteorologists, oceanographers, hydrographers, and engineers of different research institutions, who use the data of the buoy in various ways and for different scientific tasks such as wave modelling or climate modelling. The climate models have a variety of purposes—one of which is to develop forecasts of oceanic futures, of what can be expected of them in the future.

By deploying the wave buoy in the ocean, collecting and processing the data that the buoy generates, scientists acquire technically mediated knowledge about the ocean. The buoy plays a mediating role in these practices. Wave buoys do not simply produce neutral data by measuring waves, but do this in a specific way. In his article "Reading a Wave Buoy," Helmreich (2019) focuses on the Directional Waverider buoy, which also plays a central role in my research. It is one of the most widely used wave buoys in the world: "The global gold standard in directional wave measurement" as the manufacturer, Datawell, states on its website (Datawell, 2022). Utilising the Directional Waverider, Helmreich (2019, p. 740) develops the argument that the buoy can be read in different ways: as a commodity, as a manifestation of territorial dominance, or as an embodiment of media ecologies. At the same time, the buoy reads waves itself through sensing practices (Gabrys & Pritchard, 2018). The buoy's sensory capacity—its ability to sense or read the waves—is conditioned by its specific materiality, the way it is built, and the technologies used, highlighting that technology is never objective (Benjamin, 2019). Therefore, the materiality of the buoy, and how it is built, shape what it senses, or what can be sensed (and thus known) in a particular way, or as Helmreich writes, "*what kinds of waves* are considered matters of concern by various anticipated users (e.g., storm surge waves that follow hurricanes, waves that batter oil platforms, waves that can be read as signs of sea level rise)" (2019, p. 741). Buoys are therefore "solid pieces of technology, but they matter within a comprehensive set of practical, social and political relations" (Hastrup, 2012, p. 18). The wave buoy is thus not a neutral but a socio-material artefact that is politically and socially powerful insofar as its inscriptions (Akrich, 1992) configure what is important by making specific characteristics of waves visible (while perhaps rendering other aspects invisible).

In *A Book of Waves*, Helmreich (2023) describes how waves off the coast of the Netherlands are "domesticated." A large-scale infrastructure had been built and is still maintained for this purpose. An important part of this infrastructure is the wave buoy, which has been integrated into it; however, its role goes beyond just measuring waves in the ocean—it also provides data for a "global information system" as described by Edwards (2010). To establish this global information system, various interlocking infrastructures have been maintained and further developed since the 19th century to record and make the phenomenon of global climate change comprehensible. This system consists of instruments that measure the Earth vertically and horizontally, such as weather stations, satellites, aeroplanes, and ships that make it possible to measure climatic conditions such as temperatures, or the use of water gauges that measure water levels and wave buoys that measure waves (Edwards, 2010, p. 4). The scientists I worked with contribute to this knowledge on the climate with wave buoys that measure waves which are then transformed into data and models. Lovis, one of the scientists, gives an overview of the process:

> I think it's quite good, we've talked about how you collect data, how you then process the data, and that the best thing to come out of it is an explanation of what you've seen and why….That actually describes the whole process, what we do [laughs]. (Lovis, interview)

As Lovis explains, the knowledge they acquire is produced through practices in which each step relies on the one before and after. The buoy is thus part of a data transformation chain in which knowledge that takes the form of scientific explanations is produced through "translation" processes (Latour, 1999). Following Callon, I understand these translation processes as (hierarchical) relations through "which the social and natural worlds progressively take form" (1984, p. 224). In these translation processes, scientists make decisions while speaking on behalf of the buoy and its data. But these processes also transform how the ocean is perceived, how data are produced and circulated, and thus contribute to a scientific form of ocean literacy.

The wave buoy primarily assumes the function of a "reference" in two respects in this transformation process. In relation to other sea state measurement methods (e.g., from a radar), it is regarded as "something like the 'standard' against which all other methods must be validated to be recognised" (Kay, interview). At the same time, its role in the climate modelling process is to validate the calculations. The buoys' data are considered observational data, whereas the climate models are considered differently insofar as they primarily calculate with model data and are driven by these. The results of these calculations are compared with the observed data from the buoy. The "model world" is therefore constantly being compared with data collected in the water. In other words, the wave buoy mediates between the "model world" and the "observable world" or the sea; it builds the bridge and the reference that can validate what happens in the "model world."

In this process of validating the "model world" by acting as a reference, the wave buoy does not just measure the waves and send these measurements to the "land" in the form of data, but it interprets the data themselves, as Lovis tells me in an interview (Lovis, interview). This interpretation already happens before the scientists deal with the data. The interpretation can be understood as a kind of correction. If something is implausible, which means measured values do not correspond to the physical laws that are programmed into the buoy, the buoy corrects this. The buoy therefore "knows" what waves should "look like." When I ask how the wave buoy does this, Janne, another scientist, replies:

> [Measuring] direction is very exciting from a technical, metrological point of view, because it is always said that swell is frequency-direction spectrum, which is what such a buoy spits out. But this is actually an estimate. So, it is estimated from the movements of the buoy what the frequency-direction spectrum is most likely to be. It's not a directly measured spectrum. (Janne, interview)

This estimation takes the form of equations that are based on statistical distributions and are programmed into the buoy. The equations assume a normal state of how waves should be depicted in the measurements. If the measurement of the buoy does not represent this, what Janne calls the "filters" in the buoy intervene in the measurement, "which ensure that what the buoy measures is as close to reality as possible" (Janne, interview). These filters are technical methods that involve "Elektrotechnik" (Janne, interview) and signal processing. Therefore, the filters clean up the buoy's measurements whenever there are outliers and where what is measured is not understandable as "waves" to the scientists sitting at their desks looking at the data. However, Janne describes that these "filters…sometimes [do] funny things with the waves" (Janne, interview), for example when these do not correspond to the "normal conditions" to which the buoy is exposed in most cases. Then the filter "can suddenly do things that look like waves" (Janne, interview). When such cases occur, the scientists' "hand tools" are required in the form of a plausibility check. These tools are based on an experiential knowledge that the scientists build over time to recognise and explain inconsistencies. But even here, says Janne, you may get something wrong (Janne, interview). In other words,

"normal conditions" for sea conditions are defined so that outliers can be adjusted to this norm by the buoy itself and the scientists. This experiential knowledge shows that the scientific practices are based on several forms of knowledges. These scientific practices, or these scientific forms of knowing the sea, concerned with the measuring of the waves are part of what I call the laboratorisation of the North Sea. In laboratories, everything is standardised, extracted, and transformed. It is a place where the social and natural order are relationally reconfigured by all the actors—human and nonhuman—involved (Knorr-Cetina, 1992, p. 134). Therefore, the laboratorisation of the North Sea aims to make general claims about the ocean and make it legible.

For Lovis, dealing with these inconsistencies means above all that scientists must be aware that the buoy serves as a kind of "mediator." The surface deflection itself, i.e., the waves, cannot be recorded in themselves; instead, there is only what the buoy senses and conveys. As it has a large, heavy body, it cannot record every small wave: "Yes, the buoy itself interprets the data. So that's something you have to be aware of, that the buoy doesn't contain the truth, but only what it sees and what it interprets itself" (Lovis, interview). In addition to the aspects that the buoy selectively mediates—thus creating the basis for the scientists to grasp the ocean in a particular way—Lovis also describes an observation that certain waves cannot be interpreted by the buoy and are not adapted to the norm:

> What fascinates me is that you can do as much research [on extreme waves] as you like. In the end, they do what they want….You always try to approach things neutrally. But at some point, you have an idea of what it should be like based on experience. And then you look at the measured values, and it's different. And I think that's kind of great [laughs]. I always have the feeling that nature is winning against me, and that's how it should be [laughs]. (Lovis, interview)

This clearly shows that the strategies used by scientists to make waves comprehensible are only possible within a limited framework. The laboratorisation of the North Sea builds on the mediation by the buoy by inscribing assumptions in the form of reference values, in mathematical equations, and by providing already interpreted measurement data. Therefore, the ocean literacy that emerges here is based on the practices of the scientists around the wave buoy, its data, and the buoy itself, which makes it possible for the scientists to produce knowledge about the waves in the first place. At the same time, however, the waves in the form of measured values behave in an unpredictable way on a regular basis. "Nature," as Lovis notes, repeatedly eludes and "wins" the dance around the rules of physics that guide the expectations of the scientists, which have to be defined and revised again and again by scientists because the ocean behaves differently than expected. The scientists need to be limber and supple towards the sea as they produce knowledge on this flexile and mediated basis that is the sea. The laboratorisation of the North Sea, which aims to make the waves understandable through translation, is therefore built on a supple foundation, which I will explore in the next section.

3. The Wave Buoy as a Sentinel: Territorialising the Sea

The wave buoy watches over the waves off the coast; it is a "sentinel," a "guard of the bay" (Helmreich, 2019, p. 744). For the buoy to fulfil this task, the North Sea must be datafied and infrastructured. The infrastructure serves the purpose of enabling people to continue living on the coast in the face of rising sea levels and extreme weather events. Storm surges, especially those with serious consequences such as

those in the Netherlands in 1953 or on the German North Sea coast in 1962, which caused dykes to break and many people to die ("Sturmflut 1962: Als Hamburg im Wasser versank," 2024), make it clear that the North Sea requires this attention. Knowledge is needed about the water's behaviours because water is always in motion and can become threatening. Sea state forecasts help to produce knowledge about the North Sea and to initiate measures to better prepare for and prevent such threatening and momentous events. This effort to infrastructure the North Sea, however, indicates that it is seen as land. Even the buoy, which is part of that infrastructure and is deployed by humans in the sea, is oriented towards the shore insofar as humans want to have knowledge about the sea to protect the land, namely, to turn it into a territory. I use the term "territory" derived from the Latin *terra*, which signifies earth or land, and is defined as "area, country, district; land" or the "territory of a state, domain" (Territorium, n.d.). On the one hand, this indicates that the North Sea is thought of here in terms of land, and, on the other hand, that territories are associated with an exercise of (state) power. One of the aims of this, what I call territorialisation, is to preserve the North Sea coast as a living space for people by dealing with the water, by turning it into a territory. To do this, threats and unpredictabilities like stronger storm surges, warmer water, and rising sea levels due to climate change need to be managed.

However, this motivation to "territorialise" the sea by making it an object of prediction and governance also extends to other areas, and has its own specific history. For instance, military interests continue to characterise the development and advancement of the precision of these wave and wind forecasts (Van Dorn, 1974). Wind farm operators in the North Sea also need this information to build appropriately robust wind farms (Janne, interview). Shipping companies, fisheries, and oil platform operators use the information to navigate (field note, April 24, 2024). The sea state forecast is based in part on the data measured by the buoy, which monitors the waves as a sentinel. Numerous users, who all need the knowledge to understand the forecast, use this information. This is another kind of ocean literacy that I call forecast literacy.

These processes of forecasting the sea have one goal: The ocean is to be datafied and thus made tangible, accessible, and navigable. Datafication refers to a knowledge-production process in which qualitative, perceptible aspects of life are transformed into quantitative data (Ruckenstein & Schüll, 2017, p. 261). However, to be able to measure waves at all, an infrastructure is required (cf. Larkin, 2013). To build this infrastructure, knowledge, data, "practices, materials, and settings of infrastructuring" (Blok et al., 2016, p. 3) are brought and held together in a constant process. Nadim (2021), for instance, describes this data infrastructure or data-mediated relational constellation of humans, materials, and places as "data formations." The buoy's data are thus related to a variety of different kinds of data, bodies, and materials. They continually form an infrastructure that sustains the existence and proliferation of data, while also ensuring that the sea can be used in a safe way as a "territory." Yet, it is important to note that the assumptions and decisions inscribed in the wave buoy are not neutral but follow certain knowledge hierarchies. In this way, hegemonic descriptions of the world prevail (Nadim, 2021, p. 68) through the hierarchies inscribed into the way these data describe the world because the datafication of the ocean serves particular interests of humans for managing the ocean.

The infrastructure for gathering these data is made up of several relational elements. There are the maintaining practices around the buoy itself, trips with the research vessel (which must be ready to sail and equipped accordingly), nautical charts, weather and sea state forecasts (which also come from the buoys), the expert and experiential knowledge of the scientists and technicians, the navigational buoys and other markers in the

water, all the technical equipment on the ship that makes it possible to sail smoothly, the crane that lifts the buoys out of or into the water, GPS probes and data, the programmes with which the positions and data are checked beforehand, and the wave buoy itself. It is a large and complicated network of different elements, which are relationally intertwined: The buoy relies on the network and the processing of the North Sea as an infrastructure and the infrastructure of the North Sea relies upon the sea state predictions that the buoy provides. In other words, there is a mutual dependency between the maintenance of the infrastructure and the buoy. If errors or problems occur in this interdependent relationship, the buoy will not be able to fulfil its task of measuring the waves, which, in turn, makes the infrastructure "visible." This mutual dependency shows that there needs to be a constant process of adapting to the conditions of the sea. Like the knowledge practices of the scientists, this infrastructure also needs to be limber. It is the *excess* of the buoy that indicates this suppleness. Building on the work of Rheinberger (1994, p. 77), I refer to excess as a term that describes the unforeseen or unplanned events that happen in laboratories or "experimental systems." In order to deal with this excess, the scientists' handling of the buoy and the work around it follows structured procedures as part of the laboratorisation of the North Sea.

During maintenance trips, it becomes clear how much the employees on the ship have to work together and rely on the infrastructure. If this workflow is disrupted by various factors, e.g., a swell that is too rough, or if individual team members behave in unexpected ways, the situation can become dangerous and everyone is aware of this. The buoy monitors this potential danger because the ship will only sail when the forecast looks good enough. However, the suppleness of the infrastructure becomes visible when the excess of the buoy manifests in the buoy's behaviours, like when it is "dancing across the deck like a wrecking ball" (field note, April 24, 2024) while hanging from the crane, or when the buoy cannot be found in the water, or when the ship cannot approach the buoy due to excessive waves and unfavourable winds, making it inaccessible. The buoy therefore watches over the network; it indicates through its excess that the infrastructure needs to be flexible.

The constant processes of maintaining a limber infrastructure are necessary because the coast is a space of interaction (Janne, interview) in which a lot of movement takes place. People's attempts to understand this better with the help of the buoy, and to take measures to control these changes and movements as best they can, are, in turn, part of the process of territorialising the sea. This "maritime territorialization" (Roszko, 2021) is likewise visible in terms of the division of economic zones. The buoys are maintained by the respective institutions within these zones of responsibility. With the economic zones, concrete borders are defined for the space that is then called, e.g., the "North Sea" or the "German Bight."

But the ocean is a contradictory space. While it is a space that is constantly under processes of domestication and territorialisation by humans, to produce knowledge, generate data, and constitute territories, it is also, on the other hand, untamable or controllable, as Helmreich (2009) and Roszko (2021, p. 9) have described. In this tense relationship, the buoy is part of domestication, of making the ocean knowable, and of establishing it as a territory, as an extension of land, and yet it makes clear that the ocean cannot be domesticated when, for example, the buoy breaks free because the swell is too strong, that is, in its excess. In conclusion, the wave buoy indicates through its excess that the infrastructure needs to be supple like the sea, both in order to ensure its maintenance as an infrastructure, and also to provide forecasts and protection for people who live along the coast—in other words, to be able to constitute the sea as a territory.

4. Riding the Waves

In this section, I turn my attention towards the wave buoy in the sea. I will show how the buoy rides the waves and how this is intertwined with practices of surfing and the infrastructure that needs to adapt. The buoy, with its large, heavy metal body, moves freely in the waves thanks to a rubber rope but is simultaneously fixed to the seabed by a heavy iron weight, an anchor. The rubber rope keeps the buoy in check; it determines the radius in which the buoy is allowed to "dance"; it is flexible and at the same time firm—or, in other words, supple. The rules according to which the buoy dances are determined by the waves, but also by the people who built it, positioned it in a specific place, tied it down, and anchored it. However, the buoy regularly breaks out of these rules. Referring to this as excess (Rheinberger, 1994), the scientists' handling of the buoy is often geared towards managing the uncontrollability of both the buoy and the ocean. The excess of the buoy shows that the investigation of the waves is made possible only by an infrastructure that, too, is limber and in a constant adaption to the sea.

As one scientist told me, the word "buoy" is not really a suitable term for the wave buoy, but, instead, "waverider" is much more appropriate because that is what the wave buoys do: They ride the waves (field note, May 9, 2023). The word "buoy" is in itself a collective term that combines a variety of different floating bodies. Some serve as "red or green fairway marker buoys" (Janne, interview), others mark harbour entrances and swimming areas, or indicate where divers and swimmers are located. However, these buoys are rather passive: They are not supposed to move but remain in the same place or are passively pulled along to mark a specific point in the water. The wave buoy, in contrast, works differently. The rubber rope allows it to ride waves, to, as they say, "dance" in the waves. In fact, the rubber rope turned out to be very central to the scientists' ideas:

> Actually, I then only see this rope in front of me in a very scientific way. So then…I just see in front of me the diagram of how the buoy lies in there, like a cut through the water, where you can see that there is a heavy anchor chain at the bottom and then this rubber rope. And then I look at the rubber rope and hope that it will hold and that the buoy will really be able to dance there and that it will be held in place. (Lovis, interview)

Two aspects of this quote seem relevant to me here. Firstly, the rubber rope gives the wave buoy the room it needs to dance. At the same time, it limits the radius in which it is allowed to dance. This can be up to 20 meters (Janne, interview). The buoy is held in place and generally does not move anywhere else. However, Lovis already indicates here that they expect the buoy to break free. Another aspect is the imagination of the buoy in its environment. Lovis, for instance, speaks of a "scientific way" of looking at the buoy, through the idea of a schema, or diagram, a section through the water in which all the components that hold the buoy in place and make it dance at the same time are imagined in a two-dimensional view.

Janne describes the purpose of the wave buoy differently. It is supposed to measure the wave spectrum (Nielsen et al., 2023), i.e., the surface deflection of the water surface. The scientist describes the mobility made possible by the rubber rope as follows:

> The idea is that you want your buoy….So, it should stay at the place where it is supposed to measure the swell spectrum, so to speak, but at the same time it should be free, as free and unhindered as

> possible to follow the circular paths that such a wave makes on the surface, on the surface deflection. (Janne, interview)

However, the buoy sometimes has difficulties following the waves on the surface. If the waves are too high, it "can be pulled through the crest" (Sanja, interview) and then measures inaccurately:

> And then it can also be when the waves are very high and then actually the most interesting thing for me is that the buoy goes with the wave, but then, before it reaches the crest of the wave, it slips a bit and slides past it. It's a well-known fact that buoys often don't hit the top of the wave at all [laughs]. (Lovis, interview)

This happens because the buoy can only reach a certain height with the waves due to it being anchored and the limited length of the rubber rope. The rubber rope often cannot withstand very high waves and breaks regularly (field note, April 25, 2024). Due to its relatively large and heavy body, the wave buoy also cannot perceive very small waves. Its dance therefore only takes place in a certain wave height spectrum.

This demonstrates that two contradictory requirements are placed on the buoy, namely, that it should remain at a fixed point while still moving freely with the waves to measure them accurately. The fixed point is important because the measurement data are aligned to this specific point and the measurements should be comparable. At the same time, waves are always in movement, and it is precisely this movement that the buoy should record by dancing. In the imagination of a physical model, the circular paths of waves always have the same effect. If one realises that the water surface is constantly changing due to various factors, such as wind, the circular paths may still be physically (explainably) the same, but waves can come from different directions, intersect, overlap (Lovis, interview), and get whipped up or flattened by the wind. These circular paths, the surface deflection, can therefore be very different. In addition to the peculiarities of the waves, the buoy also regularly defies the rules of dance due to its design and the material used, and, above all, the conditions of the sea.

I am told that some buoys regularly break loose. For example, one "sits" in a place where extreme waves often occur. A scientist shows me a graphic with the words: "We had a [buoy] that went on a journey, 900 kilometres in a week" (field note, April 24, 2024). The buoy ran aground on the island of Sylt and had to be collected there. One of the scientists then calculated the distance and the path that the buoy had travelled in the water. As the radio frequency was not sufficient on the way through the North Sea, the measurement times stored on the SD card could be used for tracking, as fortunately the buoy's battery level was sufficient. The tracking, which resulted in a graph, also shows the tide and the speed at which the buoy was travelling (see Figure 2). The graph of the measurement times provides information on how the buoy was moving. The scientist explained why the buoy made a long circle in the North Sea and finally landed again on an island just north of its actual location by comparing the wind directions of the respective days. The wind had influenced the drifting direction of the buoy. Another buoy was found in the middle of the dunes of an East Frisian Island (see Figure 3). Explaining this and translating it into a graphic followed a similar procedure. The buoy must have "wandered" across the island during high tide, and when the island was probably flooded.

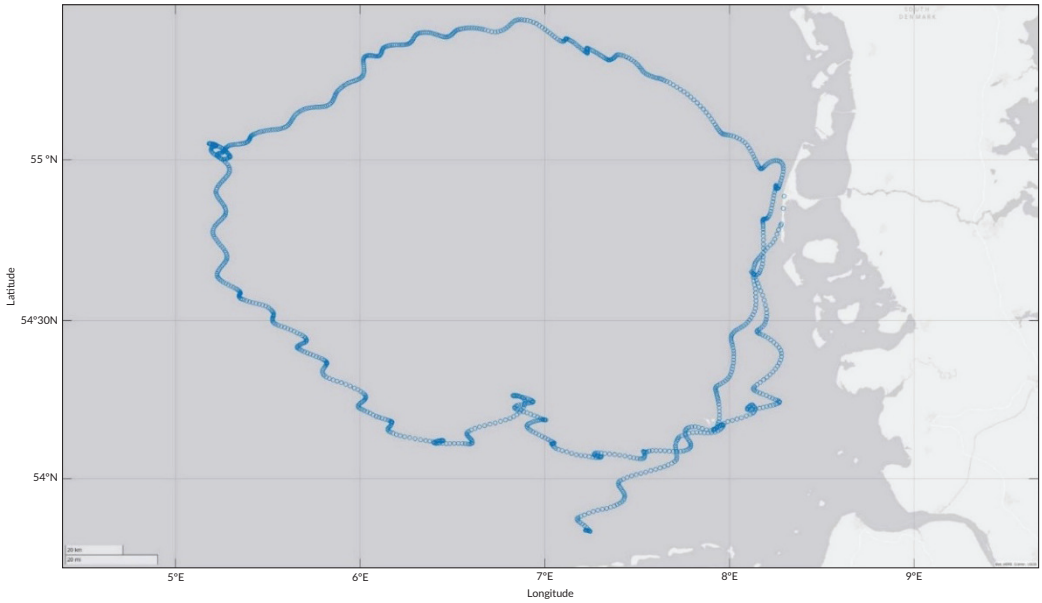

Figure 2. The travelling of a buoy in the North Sea. © Produced by members of Forschungsstelle Küste des Niedersächsischen Landesbetriebs für Wasserwirtschaft, Küsten- und Naturschutz (NLWKN).

Figure 3. A buoy in the dunes. © Produced by members of Forschungsstelle Küste des Niedersächsischen Landesbetriebs für Wasserwirtschaft, Küsten- und Naturschutz (NLWKN).

An additional factor in enabling the buoy to ride the waves is keeping it as undisturbed as possible: A special smooth yellow paint is used to prevent mussels and algae from settling on it; they are removed with a strong jet of water during maintenance trips if they are still able to latch onto it. This is done to preserve the ability of the buoy to move symmetrically with the waves. Zinc sacrificial anodes are used to prevent the metal of the wave buoy from corroding in salt water. Maintaining this standardised condition is an extensive undertaking in view of the numerous excessive "impairments" caused by the sea. All of this, from the rubber rope and the slack of the anchor to the removal of mussels, shows that the infrastructure which keeps the wave buoy riding the waves needs to be as flexible and supple as the sea itself. Hardening the infrastructure would make it impossible to withstand the conditions that the sea imposes on it.

On my surf longboard, I too want to dance on the waves. I too need to be as supple as the sea. Surfing is also known as "wave riding." Just like the buoy, I perceive the waves in which I move with my surfboard; I drift in them, but I also control my position so as not to be carried too far away from the shore by the current or the wind. As a surfer, I use the surf forecast which is based on the data from the buoy. The forecast informs me about the waves coming in on the coast. I know how to read the forecast and decipher the figures in it. I have forecast literacy.

When I go surfing, I check the wave forecast every day, either in the form of an app or a website. The surf forecast is based on the same principles as the forecasts that scientists use, for instance, to calculate storm surges. Gerrit, another scientist, describes what needs to be done with the model's prediction in their work:

> In other words, you trust that the models will be able to roughly calculate [predictions] into the future. And part of it is, of course, that you then look to see when this model has finished calculating, has made a prediction, and, at some point, this point in time will occur. And then you know what it really looks like. And then you look, did the model calculate roughly correctly or not? (Gerrit, interview)

Gerrit states that the more likely case is that the model did not calculate correctly. The comparison between what the prediction indicates and what is then found in the water (mediated by translation processes) can differ greatly. Gerrit describes that the wave buoy data have a very high temporal resolution (Gerrit, interview) and therefore cover shorter time periods better, whereas model data, for example, cover much more widely separated points in time. These high-resolution data are visible, for example, in the hourly wave forecast for surfing. On surf-forecast.com or surfline.com, like everyone else who wants to go surfing, I check which direction the waves are coming from, how high they are, what the swell period and wave energy are, which direction the wind is coming from, when it is high tide or low tide, and I use the map to decide where a surf is most likely to be suitable for my surfing level and preferences. That is step one. Step two, however, cannot be deduced from the data. For this, I need the experiential knowledge about the ground at the surf spot, the orientation of the bay, whether it is sheltered from the wind according to the wind direction, and the effect of the tide at the specific location. Step three is then the "spot check" or "wave check" to see whether the conditions correspond to the forecast. Step three also shows how many other people are already surfing in the water; people who have made the same comparison with the same knowledge. It is only after this final check that I put on my wetsuit and go surfing. Thus, in everyday practice, I compare the model forecast in the form of a surf forecast with the conditions I find on the spot. I become a mediator like the wave buoy. I too relate the forecast figures to the waves that I can observe and experience, a process that is not dissimilar to that of the scientists who check the accuracy of the model calculations with the observations of the wave buoy.

In addition to forecast literacy, I need this embodied knowledge to be able to read the waves that I can observe because I already know how they *feel*. When I am in the water I feel the tension between the ocean and myself: I can sense the energy in the waves, how I float with my board, and how small and insignificant I am in relation to the ocean. This knowledge makes clear to me that I cannot control the ocean and that I am at its mercy and its excess. Hence, I should behave according to what I know. This, in contrast to the scientific form of literacy, or forecast literacy, is an embodied form of ocean literacy. Since I cannot control the waves, I try to find a way to deal with them, and this may include not going into the water because I cannot and do not want to control the situation. These embodied and experiential knowledges help me navigate in the water. I know something about the bay where I want to go surfing: what the sandbanks are like, where I can best position myself, where the current is that will take me into the "line-up," and what the tide is like. These knowledges and practices connect me to the wave buoy as I move in the water in the same limber way, relying on the buoy's work in the form of the surf forecast, the supple infrastructure, and my embodied and experiential knowledges. It is this sea-centred perspective, becoming as supple as the sea, by riding the waves like a wave buoy, that challenges land-centred perspectives of ocean literacy.

In summary, it can be said that the wave buoy is riding the waves excessively. This shows that the infrastructure which territorialises the North Sea has to be as limber as the sea itself. Riding the waves as a wave buoy and also as a surfer, excessively and embodied, are practices pointing towards a flexible understanding of the sea which challenges land-centred perspectives.

5. Challenging Land-Centred Perspectives: A Seascape Epistemology

The efforts to understand the waves in a scientific way are based on an infrastructure that maintains the coast as a habitable space. The sea becomes, in this maintenance, territorialised through a form of ocean literacy that approaches the sea from a land-centred perspective. However, as I have shown in the previous sections, the infrastructure which is maintained to make the sea knowable is dependent on its suppleness. It needs to be as limber as the waves, flexible like the wave buoy. The buoy is not fixed in the sea, like a fixed territory, but rides the waves: It is with the water, with the wind, and with more-than-humans, like mussels or algae, and other living beings in the ocean. This connection to the water, as in my surfing, is also about feeling, sensing, and being *with* it. In this section, I am interested in how this sea-centred perspective of knowing the ocean can help us think about how the wave buoy expands the concept of ocean literacy, and what we can learn from it about human–ocean relationships.

Ingersoll (2016) turns away from land-centred perspectives to develop the concept of "seascape epistemology," which focuses on the ocean from an Indigenous perspective, as a relational place of being and knowing. This embodied approach to understanding the sea and the wind not as separate things, isolated from us, but as interconnected systems including humans is what I aim to highlight by theorising the buoy's experience as a form of ocean literacy. These systems are constantly in motion, just as I am, as a surfer, a part of them. As Ingersoll defines:

> [Seascape epistemology] is an approach to knowing presumed on a knowledge of the sea, which tells one how to move through it, how to approach life and knowing through the movements of the world….As a philosophy of knowledge, seascape epistemology does not encompass a knowledge of "the ocean" and "the wind" as things. Seascape epistemology is not a knowledge of the sea. Instead, it

> is a knowledge about the ocean and the wind as an interconnected system that allows for successful navigation through them. It's an approach to life and knowing through passageways….Seascape epistemology organizes events and thoughts according to how they move and interact, while emphasizing the importance of knowing one's roots, one's center, and where one is located inside this constant movement. (Ingersoll, 2016, pp. 5–6)

Ingersoll develops this seascape epistemology through her embodied knowledge as a surfer and Native Hawaiian (Ingersoll, 2023, p. 37). In addition to my surfing experience, my embodied knowledge of the ocean is further based on my experiences underwater as a diver since my childhood, especially in the Aegean Sea. In addition, I grew up in northern Germany with its tides, dykes, and storm surges. I therefore have a specific embodied knowledge of water, the ocean, and the sea, and this immersed positionality in and with the water and the infrastructures around it allows me to grasp how the buoy rides the waves in a sensitive and intimate way.

Seascape epistemology also points out that colonial, military, and touristic aspects cannot be ignored in the way people interact with the ocean. These aspects are intertwined with the ocean and are therefore relevant to consider: "Despite our perceived identities as organic beings, surfers are neither innocent nor benign voyagers, and our experiences and our practices often escape our intentions and philosophies" (Ingersoll, 2016, p. 4). Surfing, for instance, can involve relying on touristic infrastructure that "colonises" areas to make them accessible to surfers, while at the same time being in the water, with the water, sensing and feeling it, riding the waves like a buoy. The infrastructure necessary to enable surfing and also to sustain life on the low-lying North Sea coast must be constantly adaptable and flexible to remain as such. Seascape epistemology allows us to understand the sea by thinking from the sea and approaching life as constant movement. The excess of the buoy as it rides the waves shows the sea as a limber and supple space that needs to be understood from the perspective of the sea. The wave buoy therefore expands the concept of ocean literacy. It embodies plural ways of understanding the ocean, forcing people to understand the ocean and their relationship to it in a supple way.

Scientists who study the waves too have to adapt their practices and the maintenance of the infrastructure they rely on to the conditions that the sea forces upon them. They produce knowledge about waves and make the ocean legible through physical explanations, data, and model calculations, but this is based on the excess of the buoy. They are aware of this uncertainty associated with the excess and the unplanned, and deal with it by maintaining an infrastructure that is constantly adapted to the conditions of the sea, as supple as the sea. The scientists' relationship with the sea is therefore aimed at understanding it in such a way that action can be taken to enable human life on the coast to be sustained. This relationship means understanding the sea from a land-centred perspective.

The supple infrastructure that is maintained also helps surfers expand their embodied and experiential knowledge when they use surf forecasts and touristic infrastructure. Surfers ride the waves, know, feel, and sense the ocean in an embodied way. In this way, they are connected to the wave buoy, which also rides the waves. My relationship with the sea as a surfer is embodied and experiential; it is intimate and sensitive to it.

Embodied Indigenous knowledges, inherent in the concept of seascape epistemology, understand the sea from a sea-centred perspective. Feeling connected to the ocean can be a refuge from colonial and capitalist

structures for Indigenous colonised bodies (Ingersoll, 2016, p. 20). It can trigger and mediate reverent, unwavering peace by allowing one to drift and let one's mind wander. At the same time, the ocean can mean exactly the opposite: Even though the ocean can be seen as a refuge, a path to a better life, it becomes a grave for certain bodies through migration and border regimes. It is territorialised and militarised; it enables the transport of colonised bodies and goods. The human–ocean relationships that result from those plural knowledges are contradictory and full of tension. They are characterised by humans negotiating fear, respect, awe, humility, and strong feelings of connection, fascination, joy, and freedom. The tension is marked by a lack of knowledge and a sense of the power of the ocean, and at the same time knowing things partially and not being able to control them; it is about being in relation with what is an excess. When I go surfing, or when the conditions prevent me from doing so, I feel this tension of knowing partially and feeling the ocean, of being able to surf in partly domesticated conditions, and of the ocean's uncontrollability. Lovis also describes this tension when I ask how they think about the sea:

> I tend to have something wild in my head. I'm surprised myself, because the last time I was by the sea, the North Sea wasn't there at all [laughs]. There were only mudflats or the water was smooth. But actually, when I think of the sea, I think of something that foams and moves in all directions. And especially this thing with energy, that there is an incredible amount of energy in it and that we have already done a lot of research on it and still know very little. And we will probably still know very little in 100 years' time. So much is happening. That's why, in my opinion, we shouldn't intervene so much in all these things. We should leave nature alone for a bit….And have respect for it too. I think research also makes you respect it, because you try to explain things. But you realise that you can only explain a very small part of it. (Lovis, interview)

Lovis advocates for being a little more modest, doing less shipping, and exploiting the sea less (Lovis, interview). This would be an approach to not only manage the North Sea but to change the way we deal with it.

In summary, the buoy's excess, my embodied surfing knowledge, and the scientists' way of knowing show that different knowledges of the sea exist and that the contradictory characteristics of (not) knowing and (not) controlling reveal the plurality of ocean literacies because (human) endeavours to understand and be with the ocean vary greatly. Attempts to territorialise and domesticate the sea are linked to the management of the water, to make it accessible and usable for economic and military purposes. But for some, the ocean is also a refuge, a place of peace and tranquillity. It is a place that deserves respect, whether in a threatening or in a reassuring way. In other words, the sea needs to be understood as a supple place, and knowledges and practices need to be as limber as the sea itself, even when they are contradictory and full of tension. I have shown that land-centred perspectives are challenged by the wave buoy and that the different ways of having relationships with the sea lead to a plural understanding of ocean literacy.

6. Conclusion: Ocean Literacies

This article focused on the question of how the wave buoy expands the concept of "ocean literacy," and what we are able to learn from the buoy about human–ocean relationships. Through my focus on the wave buoy, fieldwork with different kinds of scientists, my positionality as a surfer, and the concept of "seascape epistemology" (Ingersoll, 2016), I argued for an expansion of the concept of ocean literacy, to turn it into a plural concept, that is, I argued that there are many ways to read the ocean, there are "ocean literacies."

I showed that all these different relationships with the sea are based on the suppleness of the sea, insofar as the sea requires one to always adapt; both the wave buoy and I as a surfer seek to align with the sea's suppleness, going with its flow, riding the waves. But also, in contrast to the solid and inflexible view of infrastructure, the infrastructure used and maintained to gain physical knowledge about the waves, to model possible outcomes, has to be as limber as the sea, as the wave buoy showed with its excess. The extension of the concept of ocean literacy to ocean literacies is based on my finding that there are plural knowledges of the sea and that some of these knowledges grasp the sea from a sea-centred—from the middle of it—rather than a land-centred perspective.

The wave buoy, through its excess, furthermore shows that understanding the sea as an expansion of the land, as a territory, does not grasp the suppleness or limberness of the sea and the need for constant adaptation of infrastructure to these characteristics. A sea-centred perspective allows for conceptual rethinking and includes embodied and Indigenous knowledges. Understanding ocean literacy as a plural concept, as ocean literacies, is a first step towards recognising and respecting plural forms of knowledge and thinking from a sea-centred perspective.

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Conflict of Interests

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ARTICLE

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Getting Off the Boat: Re-Considering Research Responsibility and Knowledge Dynamics in Ocean Literacy

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Abstract

In light of the UN Ocean Decade's calls for increased ocean literacy, what can critical perspectives on inter-epistemic exchanges contribute to the practice of researchers themselves? Herein, we aim to expand on scholarship analyzing the relationship between researchers and local/Indigenous knowledge holders beyond notions of knowledge commensurability, towards interpersonal practices. A framework of relationship-building allows local perspectives and knowledge to be included both actively and passively in research. However, this requires marine scientists to spend time disembarked from sampling vessels in local communities. This adaptation in research methodology involves the scientist becoming a person first, and a researcher second. A paradigm shift occurs where the researcher's function is that of a guest, whose primary exercise is to actively listen. This repositions ocean literacy as a reciprocal process, whereby the scientist learns from diverse perspectives to inform and enrich mutual understandings of the ocean. We build here on research experiences to show how interpersonal relationships, rather than systemic ones, can help build richer collaboration. This dynamic is illustrated through the case of a marine habitat mapping study in the Canadian Arctic. Community engagement was prioritized by the researcher as a first step, allowing for exposure to local understandings of the ocean to orient research questions. Outcomes included locally relevant marine maps and research findings, culturally responsive outreach materials, a recovered airplane, short-term local employment, and long-term relationships which continue to the present day. This case demonstrates how the intentional development of interpersonal relationships can leverage research activities towards building ocean literacy which respects and recognises diverse knowledge systems.

Keywords

Arctic; Indigenous knowledge; knowledge politics; local knowledge; marine mapping; ocean literacy; ocean research

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1. Introduction

At the culmination of a two-year marine habitat mapping graduate research project, the maps are finally ready to share. It is a joyous, triumphant feeling to return to the arctic hamlet outside of which these machine-learning-rendered maps of the seafloor took place. Upon displaying the final habitat maps to the municipality, hunters and trappers, and anyone interested, the response was unanimous: "We know." These AI maps only mirrored what is already known in the community. Despite this oversight, I am invited to participate in a fishing excursion in the waters where these maps predicted I would eventually go for nourishment. At the crest of my master's project, I am a beginner student of the ocean anew.

Research is full of chance encounters that can inspire us to reconsider what we know and how we know it. Drawing on such an experience and inspired by the UN Ocean Decade's call for increased ocean literacy around the world, we want to encourage a critical perspective on the knowledge dynamics which are at play in ocean science. In this article, we argue that a paradigm shift is needed in how ocean research is conducted, including attention to a more reciprocal concept of ocean literacy. As the importance of incorporating local and Indigenous knowledge in research gains academic recognition (Adams et al., 2014; Sjöberg et al., 2018), we follow others who have expanded the concept of ocean literacy outwards from its original educational framework, to include aspects pertaining to the social importance of oceans and the contributions of local experts (McKinley et al., 2023). Examining the contributions that ocean literacy research can make to policy discussions, McRuer et al. (2025, p. 5) argue that "there exists a collective need to prioritize place-based considerations and dismantle structured affiliations that have stagnated." We agree with these authors and propose that researchers take it upon themselves to develop relationships with local knowledge holders, directly embodying the change needed to produce insights into marine environments. Reconsidering the researcher's responsibility and awareness of their place in larger structures of knowledge and power dynamics can help to address current challenges in ocean literacy. Further, we argue that this shift in approach contributes to new opportunities to recognize, support, and learn from rich and diverse ocean knowledge systems. In addition to the policy-oriented call to collaboration of McRuer et al. (2025), this article contributes to the broader discussion through the study of a practical case that demonstrates how on-the-ground actions of individual researchers can contribute to fostering the reciprocal relationships needed to further an ocean literacy paradigm inclusive of many knowledge systems.

To support this, we begin by establishing the current knowledge dynamics upheld by scientific research practices. Acknowledging multiple ways of knowing the ocean requires recognizing how an individual's perspective and relationships shape their understanding of marine environments. Believing, as others studying ocean literacy initiatives have also highlighted, that multiple ways of knowing the ocean are valuable (Lobo & Parsons, 2023; Schwerdtner et al., 2023), we then discuss how academic science has maintained dominance over other ways of knowing the world (Niner et al., 2024). Through this, we highlight both the structural challenges that impede the equal recognition of local and Indigenous knowledge and the ways that researchers can adopt practices in their work to overcome these difficulties.

With an understanding of how researchers can situate themselves, we turn to a practical case to highlight how our position can be upheld in research activities. This case—part of one of the author's master's marine fieldwork—is an instructive example of how stepping off the boat, and into the community to build relationships can lead to mutual benefits, producing more robust science that recognizes and respects local

expertise. Getting off the boat in this instance is literal, but we believe it serves as a metaphor as well, encouraging researchers to find ways big and small to engage with local communities. The author's case exemplifies our position that relationship-building allows the integration of local perspectives and expertise into the work, all while contributing reciprocally to the community in which they are a guest. We believe this to be one of many required strategies, something to be practised alongside the supporting of local and Indigenous-led research (Held, 2019) and even the active stepping back of researchers to "make room" for Indigenous knowledge in institutional settings (Latulippe & Klenk, 2020). Which approach to apply in a given scenario is something that must be carefully considered alongside local and Indigenous peoples, hence the importance of developing interpersonal relationships. For marine scientists, this entails venturing beyond their vessels to engage directly with coastal communities.

Before beginning, we believe it is important to recognize our own positions concerning the knowledge dynamics we discuss. While legitimate critiques of practices such as positionality statements have been offered (see, for example, Gani & Khan, 2024, who examine how these statements can reify the privilege of those making them), our experiences working in Arctic communities have seen explicit requests by community members for the inclusion of such acknowledgements in academic writing. In this regard, the authors wish to acknowledge that their educational backgrounds have been in Western academic institutions, that they have had the privilege of support for their scientific research from major funders, and that they are based in southern Canada. The primary author is of settler-Canadian heritage, while the secondary author is of dual settler and displaced heritage, and is a woman of color. From these positions of privilege, we have aspired to learn from local experts and Indigenous knowledge holders with humility, and thank the people of Pangnirtung, Nunavut on whose lands and in whose waters the research described took place.

2. As Many Oceans as Ways to Know Them

Many fathoms under the sea, the delicate tendrils of feather stars sway gently in the cold passing current. Illuminated by the electric glow of lights mounted on the Remote Operated Vehicle (ROV), the seafloor of the fjord is being recorded in 4K for the first time. Local fishermen and divers, however, also know these *imammiutait*, or sea creatures, from their nets and the shallower waters of the fjord. These different vantage points in knowing the same benthos illustrate an easily overlooked reality: there are many oceans, not simply geographically, but also according to the perspectives from which we observe them.

There is more than one "ocean," and more than one way to view the same ocean (Lobo & Parsons, 2023; MacNeil et al., 2021; Schwerdtner et al., 2023). With the UN Ocean Decade's call to improve ocean literacy across the world, specifically via Challenge 9, to "ensure comprehensive capacity development and equitable access to data, information, knowledge and technology across all aspects of ocean science and for all stakeholders," we need to consider that there are many oceans to be literate on (Intergovernmental Oceanographic Commission, 2021, p. 23). This holds true for the range of conditions that distinguish oceans around the world, unique in their ecological and geological diversities, but also for different ways of knowing the same oceans. Depending on one's perspective and relationships, radically distinct aspects can be key in determining an understanding of the ocean (Gee, 2019; Jefferson et al., 2015). In this context, "perspective" refers to the unique combination of factors that shape an individual's viewpoint of the world. Perspectives are multiple and we as individuals can carry views which apply in multiple scales and scenarios, sometimes in

seemingly contradictory manners. Factors such as cultural background, knowledge systems, professional training, and even the languages they speak profoundly shape how the ocean is viewed by that person (Jefferson et al., 2021). A university-based researcher, for example, trained in oceanography and socialized in Western sciences is likely to hold a different view of the ocean than a local harvester, whose expert knowledge is the product of lived ways of knowing that same ocean.

The perspective offered of the ocean by diverse cultural and knowledge systems can challenge assumptions held by scientific researchers. Fundamental differences in how the environment is experienced and known are important in understanding how there can be multiple perspectives of the same ocean that unsettle even basic assumptions. Far from being constrained to the personal, these perspectives are highly social and often politically important (Potts et al., 2016). Maintaining and experiencing an Indigenous perspective of the ocean can be an important act of self-determination (Ingersoll, 2016). Further, affirming a perspective of the ocean which highlights commonality and connection between a region's Indigenous peoples is a means by which colonially imposed understandings can be supplanted (Hau'ofa, 1998). In referring to the impact of relationships on understanding the ocean, we are highlighting the connection between a person's social entanglements and their perspective on the world they inhabit. These relationships can be important not only for the ways that people use and interact with the ocean but also for the value their knowledge holds in different contexts (Battiste, 2005; Silver et al., 2022). The power of various perspectives on the ocean impacts ocean governance and literacy, with the difference in valuing these perspectives shaping policy, marine initiatives, and research engagements.

3. Science as One of Many Knowledge Systems

As one way of knowing the ocean, Western scientific knowledge is disproportionately leveraged in ocean literacy efforts, leaving little room for local and Indigenous ways of understanding. Currently, the majority of oceanographic research is conducted using offshore research vessels, which serve as platforms from which scientific inquiry dominates publications within the marine science realm (Intergovernmental Oceanographic Commission, 2020). The reasons for this are complex, ranging from the favouring of academic credentials and publication histories, to access to funding tied to academic institutions, to the bias towards physical science projects, all of which relate to the colonial history of ocean science (Silver et al., 2022). We want to draw attention to two factors that, with proper planning and collaborative intentions, researchers can work to mitigate. By recognizing the systemic dominance and the extractive practices of Western science, researchers can take steps to ensure that their own projects create space for more diverse ways of knowing the ocean.

As a knowledge system, science has historically been upheld in part by the idea that it provides an understanding of the world that is not predicated on biases or influences external to itself (Stamenkovic, 2022). This supposed neutrality was often used by colonial institutions to place knowledge produced through scientific practices in dominance over other forms of understanding (Niner et al., 2024; Singh et al., 2021). While rarely framed in explicit terms, the notion follows that if scientific knowledge is produced in neutral and objective fashions, then other forms of knowledge are implied to carry bias and are therefore unnecessary or incorrect. In the context of ocean sciences, this bias was leveraged by colonial governments and industry to attempt to erase Indigenous knowledge and access to rightful ocean resources (Silver et al., 2022). Critical scholars have described this as the systemic dominance of science and have examined the

various aspects, such as the "culture" of scientific laboratories (Latour & Woolgar, 1986) or the plain aesthetics of scientific cartography (Cosgrove, 2005), that act to support this power dynamic. Examining ocean governance, Tafon (2018) draws on post-structuralist philosophy to situate power in the discursive relationships between forms of knowledge. In such a framework, the dynamics of power are situated in the possibilities of discourse, or more simply, in what kinds of knowledge are considered valid for inclusion in a system (Foucault et al., 1997). Importantly, science is not a monolith but is continually produced, with power negotiated through the social practices of scientists (Albert & Kleinman, 2011). This system of power relations is important to understand as it helps to explain in part the difficulty often faced by knowledge holders in having their expertise recognized (Battiste, 2005) and the tendency in the deployment of ocean literacy projects to teach local and Indigenous communities scientific ways of knowing the ocean rather than vice-versa (see Spalding et al., 2023, for a similar critique of ocean governance).

Understanding the power dynamics of science also helps to shed light on how research can be an extractive process, sometimes due to systemic factors outside of the researcher's control. Without attempting to diminish the responsibilities researchers have, it is important to highlight that some of the factors making research extractive are structural and require considerable resources and experience to address. These resources can be more challenging for early career researchers or researchers from smaller institutions to access. In the Arctic especially, research tends to be characterized by short and intensive periods of data collection on boats, followed by long processes of analysis back in institutional environments (Gearheard & Shirley, 2007). These short summer visits often fail to produce opportunities for meaningful interaction between researchers and the communities they work in or around. Research becomes extractive in these scenarios where scientists acquire knowledge, experience, or data and then process it in their institutions without the engagement or collaboration of community members (Gearheard & Shirley, 2007; Singeo & Ferguson, 2022). Extractive research fails to participate in reciprocal relationships with knowledge holders and often fails to properly acknowledge those who have contributed towards supporting them in the field. Furthermore, the extreme cost of travel (upwards of $2,000) and accommodations ($400 per night or more) can be financially prohibitive for in-person visits to the Arctic (Mallory et al., 2018). Relatively smaller northern communities are unlikely to be visited by researchers since access may be restricted by limited transport options, lack of equipment, or insufficient accommodations. However, local radio and social media pages hosted by the communities are available channels to communicate and share research objectives with a low barrier to entry and a wide reach (Meyer et al., 2018). Despite critiques on the potential misuse of social media as scientific dissemination tools, the authors advocate for its use to enhance transparency and facilitate knowledge sharing (de Souza & Dale, 2024; West & Bergstrom, 2021). Therefore, logistical constraints are not meant to serve as a pardon for a total lack of communication or outreach from marine scientists.

Unfortunately, these practices have historically been prevalent to the extent that local and Indigenous authorities have put in place guidelines (see Inuit Tapiriit Kanatami & Nunavut Research Institute, 2007, *Negotiating Research Relationships with Inuit Communities: A Guide for Researchers*) and licensing processes to ensure more reciprocal research practices (de Vos & Schwartz, 2022). However, "umbrella" research licenses are usually awarded to large research vessels with multiple projects occurring simultaneously, thereby avoiding having numerous research license applications from one platform. As northern research licensing offices are understaffed (usually one or two people to process hundreds of applications), these measures help limit the overwhelming number of requests. However, this makes tracking results and research outputs

a challenge for research licensing bodies and the research platforms themselves. It also means much of this work is not shared with communities, as research vessels remain largely offshore during sampling, and the data is then dispersed across different academic and government institutions around the world afterwards. This dynamic perpetuates a disconnect between marine research and coastal communities, undermining efforts for inclusive ocean literacy.

The valuing of scientific practices over local or Indigenous ones is a serious concern, contributing directly to the colonial erasure of Indigenous epistemologies and ways of being (Lobo & Parsons, 2023; Silver et al., 2022). The systemic tendencies of science to be both dominant towards other ways of knowing the world and extractive in nature often result in the knowledge produced by research only returning to communities after it is finalized and cemented in the form of scientific reports and raw data. This unfairly burdens local and Indigenous experts, obliging them to operate in the knowledge system of Western science (Ortenzi et al., 2025; Trisos et al., 2021). While the importance of local and Indigenous knowledge on the ocean is increasingly recognized as necessary to broaden understanding and undo colonial dominance within ocean literacy efforts (see, for example, McKinley et al., 2023), systemic biases remain in place which tend to prioritize scientific research over other ways of knowing the ocean. Biases such as the favoring of academic credentials, or limited funding outside research institutions prevent understandings of different oceans from being considered valuable in the same way as scientific research, which can give marine researchers the impression that there is no benefit to working with local and Indigenous experts. Despite this dynamic, Indigenous organizations and governments have most effectively championed contemporary collaborative research projects. Groundbreaking works, such as the *SIKU: Knowing Our Ice atlas* (Krupnik et al., 2010), have demonstrated that long-term and reciprocal collaboration is most effective when many forms of knowledge are valued and shared. Acknowledging the multiplicities in knowing the ocean is the first step towards building a richer, locally informed understanding.

4. Opening Channels With Local and Indigenous Knowledge

A growing awareness of the systemic inequality of research practices and knowledge dynamics has led to increased recognition of the importance of local and Indigenous knowledge within discussions on ocean literacy. In their conceptual review of ocean literacy, McKinley et al. (2023, p. 2) note that:

> Echoing calls in the UN Ocean Decade, knowledge in the context of ocean literacy must acknowledge, integrate and value different types of knowledge, including and championing local and Indigenous knowledge, and recognising that diversity of knowledges and "ways of knowing" the ocean should be encompassed within ocean literacy discourse.

While such recognition is a step towards greater equality in knowledge dynamics, the centring of the knowledge itself can lead to an alienation from the cultural contexts of the knowledge holders who share it. Examples of this can be observed in the inappropriate incorporation of traditional ecological knowledge (TEK) into peer-reviewed research, and its underrepresentation in mainstream funding (Singleton et al., 2023; Wong et al., 2020). Research on the use of TEK has highlighted that the capacity for authoritative audiences to understand local knowledge leads to rewriting and assimilation into the dominant academic or bureaucratic systems (Nadasdy, 1999). In these efforts, local and Indigenous knowledge is often separated from broader ontological and cultural contexts for the sake of legibility and applicability (Cruikshank, 2004;

Nadasdy, 2005). The critiques of the uptake of TEK highlight that incorporating local and Indigenous knowledge into ocean literacy efforts without the involvement of knowledge holders is often done for the benefit of said systems, ignoring the situated, lively, and socially entangled nature of these ways of knowing the world.

Despite these challenges, there has been a growing trend in recent academic research to collaborate with knowledge holders and incorporate local and Indigenous knowledge more centrally in scientific works (Bohensky & Maru, 2011). This trend has been made possible by both an increased recognition of the importance of local and Indigenous knowledge and efforts to centre the voices of these knowledge holders through more funding streams. Said efforts emerged in pioneering works (for example Cruikshank, 2005, *Do Glaciers Listen?*) that recognized that presenting local and Indigenous knowledge in scientific monographs decontextualized and altered the meaning of what was shared. To counteract this, researchers presented knowledge as shared by knowledge holders, which was possible because of the relationships of trust and collaboration which existed between them. Ocean literacy scholarship has begun to advocate for similar approaches by adopting calls for a more multitudinous and regionalized approach to ocean knowledge (Schwerdtner et al., 2023). This progress has been slower on research vessels, where intense sampling schedules and the physical separation of the boat from shore limit direct interaction between scientists and local communities. Emerging initiatives in Canada, such as the Partnered Research Program at ArcticNet and Polar Knowledge Canada's Inuit Nunangat-led or partnered projects, mandate active engagement with Indigenous and Northern partners as part of the research. Additionally, Canada's only fully dedicated research icebreaker the *CCGS Amundsen* has recently committed to engaging with Inuit communities through its Northern Research Liaison program and collaborations with the Nunatsiavut Government for their Imappivut marine planning initiative. While promising, efforts such as these are only the beginning of bridging the longstanding divide between marine scientists and northern coastal communities.

5. Enhancing Ocean Literacy for All

The ocean is deeply intertwined with Indigenous and coastal identities worldwide (Buchan et al., 2024; Gee, 2019). These knowledge systems are crucial to ocean literacy, as they encompass not only data but relationships and lived realities entwined with the ocean. However, knowledge systems are not monolithic entities, but rather heterogeneous and interconnected across space and time, with shared growth patterns and histories (Dove et al., 2006). When considering ocean literacy, our understanding of the marine environment needs to include everyone in order to attain a more holistic scholarship of our oceans. By adopting a reciprocal approach where researchers actively listen and contribute to the communities in which they work, we can bridge these divisions and foster "two-eyed seeing." This practice, first introduced by Mi'kmaw Elder Albert Marshall, involves being attentive to multiple ways of knowing the world simultaneously (Marshall & Bartlett, 2004). Beyond knowledge integration, two-eyed seeing calls for responsible action based on the knowledge embodied in multiple perspectives (Wright et al., 2019). This collaborative approach not only enriches our collective knowledge but also contributes to building a more inclusive landscape of marine identities (Buchan et al., 2024). By recognizing and respecting multiple ways of knowing the ocean, we can cultivate a more comprehensive and nuanced appreciation of ocean systems, one that honours and incorporates diverse knowledge traditions.

With this framework in mind, the onus falls on visiting researchers to become literate in local ocean knowledge. Rather than an expert presenting themselves to transmit ocean literacy, the balance of social interaction shifts to the scientist being a learner, ready to listen. As a guest in a coastal community, the building of relationships becomes central to the work of the scientist engaged and committed to two-eyed seeing. Values involved in this process include respect (a), engagement (b), and reciprocity (c) with community members (Figure 1). These values have the benefit of creating meaningful ties to local realities, which affect the researcher's perspective of the local marine environment. The relationships fostered through these values enable the application of two-eyed seeing, where listening, learning, sharing, and integrating both Indigenous and Western ways of knowing the ocean can coexist and complement each other. By respecting (a) coastal community members, the doors to fruitful communication and sharing are opened for a reciprocal knowledge transfer, resources and logistical provisions, and long-term collaborative exchanges. Engagement (b) in this context means interacting authentically with the community, remaining present, and connecting as a person first, and a researcher second. By establishing these ties, respect and reciprocity are also strengthened. Since the researcher gains knowledge by respectfully engaging with communities, sharing (c) in return helps move ocean literacy efforts towards reciprocity. By sharing what has been learned back with the wider community throughout the research, ocean literacy enters a feedback loop, whereby understandings can be course-corrected and revised to local lived realities. These feedback loops of understanding are their own processes of enhancing collective ocean literacy when they are integrated into shared results, whereby no one perspective dominates our understanding. These methods resemble other collaborative models, such as those proposed by Reid et al. (2021) and Strand et al. (2024) for the co-production of sustainable ocean plans. By building meaningful relationships, applying two-eyed seeing becomes possible for researchers in the contexts where they are guests stepping off the boat and into communities. By honouring many worldviews of the ocean, ocean literacy can improve with a more comprehensive understanding and connection to the marine space.

The values of engagement, respect, reciprocity, listening, learning, sharing, and integrating are essential to fostering inclusive and ethical research practices that bridge Indigenous and Western knowledge systems. Engagement begins with researchers actively involving communities from the earliest stages of project

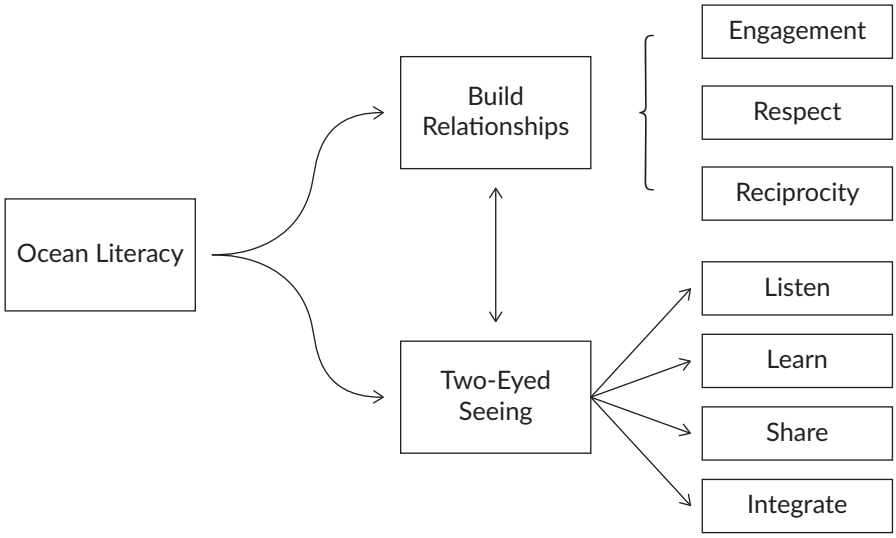

Figure 1. Conceptual framework for enhancing ocean literacy.

development, ensuring that local priorities shape research questions and methodologies (Dalhousie University, n.d.). Respect is demonstrated by recognizing Indigenous epistemologies and cultural protocols, such as incorporating traditional knowledge without decontextualizing it or privileging Western frameworks (Cruikshank, 2005; Smith, 1999). Reciprocity ensures a two-way exchange of benefits, such as hiring local research assistants or co-developing educational materials that reflect community interests (DuBois & Antes, 2018). Listening involves creating spaces for Indigenous voices to guide the research process, often through participatory workshops or informal dialogue (Dalhousie University, n.d.; Johnson-Jennings, 2023). Learning requires researchers to adopt humility and openness to understanding Indigenous perspectives on marine environments (Marshall & Bartlett, 2004; Rodriguez-Lonebear, 2016). Sharing knowledge back with communities in accessible formats—such as translated maps, comics, or public events—ensures inclusivity and accountability (Canadian Institutes of Health Research et al., 2018). Finally, integration involves co-creating hybrid methodologies that honour both scientific rigour and Indigenous ways of knowing while addressing shared goals (Marek-Martinez & Gonzalez, 2023; Wright et al., 2019). Together, these practices create a constructive direction for ocean literacy that is inclusive of diverse perspectives and responsive to the lived realities of coastal and Indigenous communities. Although conceptually these are broadly accepted, putting them into practice is challenging within the academic framework of marine science, particularly as an early-career researcher with limited funds and agency in research projects. Since marine science is often conducted at sea away from communities, leveraging the funding and the willingness of supervisors to invest time in building relationships on land is still a privilege offered to few.

6. Relationship Building on Land to Make Marine Maps

From 2022–2024, a marine habitat mapping study was conducted in two Arctic fjords by one of the authors as part of their master's fieldwork. As a research project designed and funded by a southern Canadian university in 2019, the initial goal of the research was to create habitat maps of the seafloor in Arctic fjords. An "umbrella" license was granted to the large research vessel by the territorial research licensing entity, permitting video and sonar data collection in Arctic waters in 2020 without the requirement of community engagement. In 2022, the author was selected as a master of science candidate and given the data from the research expedition for analysis. Although data had been previously collected, the project required more data in particular regions of the estuaries inaccessible to large boats. Therefore, a key first step was securing a way to sample with local vessels, a task which was not possible to achieve from a university office. An introductory visit was scheduled in the first month the student was assigned to the project, at the initiative of the student. As a marine science student, this was seen as unusual within the institution, and a lack of guidance and resources for how to proceed made this and subsequent visits an exercise in "learning by doing."

Upon arrival, the researcher prioritized community engagement, in the way a polite guest might introduce themselves to their hosts and offer any cooperation in return. Here the authors denote "guest" as a way of positioning oneself as a researcher, which comes with obligations for good behaviour as understood by the host. As a newcomer visiting a community, introducing themselves and their reason for being there was an initial step. This meant knocking on doors in public buildings, attending local events to meet community members, and striking up conversations in grocery stores and the post office. Cards with contact information and visuals of the seafloor were also left in public spaces, to increase awareness and access to more information (see Supplementary File, Figure 3). This exercise had the benefit of rapidly establishing local connections and provided the insight needed to know who to ask for permission and where to start.

For certain community members, the ability to voice concerns and questions towards the scientific study of their region was a positive prospect. To begin, the researcher sought permission from the mayor and the Hunters and Trappers Association, who gave their consent and provided valuable contacts. This led to collaboration with local fishermen who became the project captains and guides on the water. Within a week, the necessary sampling vessel, base of operations, and community ties were formed through scientific outreach and listening. The emphasis on relationship-building facilitated smoother research operations and enhanced awareness and local participation in the project.

The relationships built over initial visits and the trust reinforced in the two subsequent visits, allowed the researcher to progress in their community engagement and gauge local interests in the marine space. Interests in the community varied from academic interests, leading to different research questions forming. For example, multiple community members were interested in the distribution of Iceland scallops in their fjord. In contrast, academic pressure also led to more Western science questions being asked, such as the distribution predictions of benthic community assemblages in the fjord. Coincidentally, the maps which were generated using local interests yielded higher-accuracy maps than the ones answering questions interesting to the academic institution (83.3% vs. 69.2%; Graham, 2025). Further research is needed to clarify the underlying mechanisms contributing to the enhanced accuracy of the community-driven maps and to systematically validate Western scientific marine maps against local and Indigenous knowledge of these areas. Delving deeper into community interest-driven maps could potentially reveal valuable insights into the complementary nature of diverse knowledge systems in understanding complex marine environments using machine learning (Lauer & Aswani, 2008).

At the request of the Hunters and Trappers Association, educational outreach became a significant component of the project, even though it was not an initial aspect of the research design. The researcher presented original underwater footage to local elementary and high school students, sparking curiosity and generating questions like “Why does it snow underwater?” and “Is it always dark?” (Figure 2a). This engagement led to the translation of benthic species names into Inuktitut by the students, enhancing local relevance and understanding. Following this initial visit, the project expanded to include hands-on experiences for students. Before field sampling the next fall, high school students were invited to pilot an ROV in their harbour, providing them with direct observation of the seafloor near their classroom (Figure 2b). This practical workshop deepened students’ connection to the marine environment and the research process while enhancing the researcher’s awareness of local stories and interests in the surrounding waters. Students shared about the presence of an airplane crash in the vicinity, which led to the successful reconnaissance of a sunken DHC-3, de Havilland Single Otter airplane which sank in 1958. During benthic video sampling the following week, ROV video of the plane was captured and shared with the community, prompting further opportunities for discussions of local waters and the currents which led to the soft ice where the plane sank. This social integration via the schools contributed to a broader understanding of the community and its relationship with the marine environment for the researcher. Additionally, these outreach initiatives can be understood to have engaged students in developing their own ocean literacy learning, which Strand et al. (2023), argue to be key in better accounting for diverse knowledge systems. From these visits, the researcher hired local youth to participate in sampling and outreach activities on multiple occasions, providing employment opportunities and fostering continued community involvement in the research process (Figure 2c).

Figure 2. Community outreach examples from the case study: (a) a class outreach visits sharing underwater footage; (b) ROV piloting workshop with the school; (c) working with local experts and youth in marine sampling; (d) Benthic Bingo event in the community hall for all ages.

As an act of respect and reciprocity, cultural responsiveness grew to be a key aspect of the project through time spent in the community. In this case, cultural responsiveness was practised first by listening, then by applying storytelling, local Inuktitut dialects, games, two-way information sharing, and age-appropriate activities for youth. For example, the process of marine habitat mapping was transformed into a comic story by artist Misha Donohoe, inspired by the student's curiosity (see Supplementary File, Figure 4). The comic featured local elements such as boats, traditional clam-digging practices, and marine mammals vital for sustenance and cultural identity, making the scientific content more relatable to the community than a scientific report or infographic. The researcher's approach extended beyond prescribed marine research activities. Evening bingo and card games with new friends provided informal opportunities for knowledge exchange and relationship strengthening. It also led to the creation of a custom pack of cards using the artist's renderings of local animals, an educational gift with over 200 decks shared on subsequent visits. Once results were ready to be shared, maps were printed in English and Inuktitut, and Benthic Bingo events were held whereby the main animals surveyed were called out rather than numbers (Figure 2d). As a public event, the Benthic Bingo allowed community members to feel welcome to attend and share feedback on the presented work, which could be incorporated into the final draft. The timing of these events was also important—optimal engagement periods were outside regular working hours, busy hunting and fishing seasons, and community events such as radio bingo. To promote inclusivity, particularly for mothers, efforts were made to create family-friendly environments, thereby facilitating their attendance and participation. For those unable or uninterested in attending in-person events in the communities, local radio and social media announcements of the project were publicized and contact information was left in all public spaces for anyone to reach out with comments or concerns.

Finally, the research data was shared directly with the territorial research institutes and the municipalities, as well as deposited in the publicly available Canadian Federated Research Data Repository. This practice upholds the FAIR (findable, accessible, interoperable, and reusable) principles of data governance (Wilkinson et al., 2016), ensuring that data is widely available while considering local communities' access and storage capacities. By storing raw and processed data in formats that are interoperable and reusable (e.g., .tiff and .csv), this data serves not only to answer the current study's questions but any potential questions in the future. Sharing research data in both raw and processed forms also promotes Indigenous research sovereignty (Carroll et al., 2020). These principles guided conversations with local community members about their preferred methods of receiving the data, an approach that Ortenzi et al. (2025) refer to as fostering "good data relations." Moreover, sharing data contributes to building trust and fostering collaborative relationships with Indigenous communities, supporting their autonomy in research and decision-making processes.

This practical case demonstrates how prioritizing interpersonal relationships and community engagement can lead to more effective and locally relevant scientific research. For instance, the project integrated community-driven questions (e.g., mapping Iceland scallop distributions valued by local harvesters) and produced habitat maps that outperformed academic-driven models. Outreach initiatives such as translating species names into Inuktitut with students and co-designing culturally responsive Benthic Bingo games, ensured findings resonated with local lifeways. Additionally, hiring community members for fieldwork and sharing raw data with territorial institutes aligned with Inuit research sovereignty principles. By spending time off the boat, the project achieved not only its scientific objectives but also contributed to collective ocean literacy through its community-driven outreach initiatives and long-term connections within the community which continue to the present day.

7. Conclusion

A paradigm shift in how marine research is conducted is necessary, including special attention to the role of ocean literacy in research engagements. The authors wish to emphasize the importance of getting off the boat, venturing into communities and building interpersonal relationships with reciprocal knowledge exchanges. These practices are key to the creation of collaborative marine research which respects and recognizes diverse knowledge systems. By reconceptualizing the researcher's role as that of a guest and learner, we can foster a more inclusive and comprehensive understanding of ocean literacy.

The case study of marine habitat mapping in the Arctic demonstrates the tangible benefits of this approach, including locally relevant research outcomes, improved outreach materials and research results, and enduring relationships with community members. This shift not only enhances the quality and relevance of scientific research but also addresses power imbalances inherent in conventional research methodologies. In embracing the values of respect, engagement, and reciprocity to build relationships, researchers can create meaningful ties to local realities and integrate diverse knowledge systems into their work. By building relationships in conjunction with the two-eyed seeing framework, multiple ways of knowing the ocean can be uplifted while respecting local realities. This approach aligns with the UN Ocean Decade's call for increased ocean literacy and contributes to a more holistic understanding of marine environments.

Despite increasing efforts in ocean science to collaborate with Indigenous knowledge holders (see Keenan et al., 2018; and Laidler, 2006, for pertinent Arctic examples), our experiences working in the Arctic as early

career researchers indicate that there is still work to do in applying these conceptual frameworks of relationship building and two-eyed seeing in ocean literacy work. As a practical example, this case study had several notable limitations. Data collection in 2019 proceeded without community consent, and Inuit participation was not integrated throughout all research stages, such as the data analysis. No formal community workshops were conducted, and the research methodology remained firmly grounded in Western scientific approaches. While results were translated into the local language, Indigenous knowledge systems were not meaningfully integrated into the final analysis. This was evident from the community reaction to the final maps, as the predictive modelling of where scallops would be was already known. Additionally, the high costs of northern travel and accommodation presented significant barriers to sustained community engagement, with only about 30 in-person days in the community over two years. These limitations highlight the need for institutional support and resources to help early career researchers build meaningful relationships with northern communities. Future research should prioritize Indigenous involvement from the outset, integrate diverse methodologies, and ensure adequate funding for sustained community engagement throughout the entire research process.

Moving forward, it is crucial for the scientific community to actively work towards building relationships that facilitate two-way knowledge exchange. For ocean scientists, there are several ways this can be accomplished throughout the research process. Researchers can consider learning directly from local knowledge holders, engage local experts in collaborative research design, or disseminate plain-language summaries through appropriate channels (such as community radio stations), for example. The most crucial aspect in determining the path towards reciprocity, however, is for researchers to reach out to local communities with the intention of building a genuine and mutually respectful relationship. By doing so, a more inclusive and comprehensive approach to ocean literacy can be created which benefits both researchers and coastal communities. In getting off the boat and into communities, we create new opportunities for knowing the ocean for all.

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Conflict of Interests

Myrah Graham is currently the Northern Research Liaison for Amundsen Science and, as part of her master's research, collaborated with the Nunatsiavut Government on the Imappivut marine planning initiative, which may be perceived as a conflict of interest.

Supplementary Materials

Supplementary material for this article is available online in the format provided by the author (unedited).

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Ocean Literacy Opportunities in Urban Marine Ecosystems: Gorgonian Populations in Barcelona (Catalonia, Spain)

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Abstract

Urban marine ecology, an emerging field in marine research, presents new opportunities to promote ocean literacy and contribute to the UN Decade of Ocean Science for Sustainable Development (2021–2030). Seeking to advance these objectives, the Gorgonia Barcelona project, launched in 2021, adopted a collaborative and inclusive approach to foster collaboration among marine scientists, local scuba divers, fishers, policymakers, industry, academia, and citizens, co-producing knowledge concerning marine benthic ecosystems dominated by Gorgonians in Barcelona. This study presents the findings and methodology developed throughout four successful years of the project, offering insights that could inspire similar initiatives elsewhere. Additionally, a Q-sorting exercise was conducted to assess Barcelona divers' alignment with ocean literacy dimensions, providing a tool that can be applied in diverse contexts—an identified research priority in ocean literacy. Three main diver profiles emerged: optimistic, pessimistic, and neutral. Divers expressed concerns about the urban marine environment, demonstrating a strong desire for its improvement. The study also incorporates testimonials from visitors to the project's experimental aquatic zone, emphasising the role of older generations in fostering sustainable behaviours. Discussions with a representative of Barcelona's fishers highlight the valuable local ecological knowledge they provide, despite often feeling overlooked and left out of marine conservation and ocean literacy discussions. The findings help close knowledge gaps and highlight the need for stronger conservation efforts, as well as more sustainable and inclusive governance models in urban marine areas. They also demonstrate how coastal cities can serve as key players in advancing ocean literacy through responsible research and innovation-driven approaches that encourage sustainable actions.

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Keywords
citizen engagement; fishers; Gorgonian; *Leptogorgia sarmentosa*; Mediterranean Sea; scuba diving; urban marine environment

1. Introduction

The UN declared 2021–2030 as the Decade of Ocean Science for Sustainable Development, aiming to enhance global efforts and stakeholder engagement under the motto "the science we need for the ocean we want." One of the main objectives of this initiative is to contribute to the global ocean literacy (OL) goals (IOC-UNESCO, 2018). OL emerged as a global effort to promote an understanding of the ocean's influence on humans and our influence on the ocean. This initiative arose from the need to integrate ocean knowledge into broader societal awareness and decision-making processes (Cavas et al., 2023). Moreover, OL is not only about being ocean-literate but also about having the capacity to apply marine knowledge to make informed and responsible decisions (Cava et al., 2005). In the Mediterranean, applying OL—particularly its adapted framework, Mediterranean Sea literacy—can contribute to responsible decision-making and governance, while also contributing to conservation, restoration, innovation, and sustainability goals (Mokos et al., 2020). Following several research efforts in OL that contributed to defining and mapping OL knowledge, the concept evolved to integrate and designate the current OL dimensions (McKinley et al., 2023). In a systematic review of OL research, Shellock et al. (2024) raised several concerns and priorities in advancing OL studies to achieve sustainable ocean futures. Notably, they emphasised the need to develop monitoring tools to analyse the interrelations among stakeholders, OL "emoceans" (i.e., emotional connections with the ocean), and, particularly, trust and transparency. Additionally, reporting OL findings from different regions and contexts worldwide is crucial for a more comprehensive understanding of "the OL big picture," as OL research remains scarce and is predominantly led by a few countries, mainly the US, followed by Canada and the UK (Shellock et al., 2024).

Meanwhile, the field of urban marine ecology has gained increasing research interest as coastal urbanisation continues to expand, creating complex intersections between economic development and marine conservation. Several studies have explored these interactions, highlighting key challenges, such as habitat loss, altered water quality, and biodiversity shifts (Burt, 2014; Firth et al., 2016; Piwowarczyk et al., 2013; Todd et al., 2019). Urban marine development is often linked to various ecological impacts, such as pollution and habitat alteration. Research has documented how these changes influence marine ecosystems, particularly in terms of water contamination and structural alterations to habitats (Bulleri et al., 2020; Dafforn et al., 2015; Firth et al., 2016). Among the most significant consequences of shoreline urbanisation are the construction of dykes and breakwaters, the dumping of urban and industrial waste, and the discharge of ballast water, all of which can severely impact marine ecosystems (Figure 1).

Todd et al. (2019) highlighted the need to address knowledge gaps in marine urban areas and adopt a broader approach to studying urban marine ecosystems to improve both ocean and human health. This requires integrating ecosystem drivers, analysing future trajectories and fostering collaboration with city governments, planners, and industry. As a result, innovative strategies are increasingly necessary to better understand and manage urban marine biodiversity.

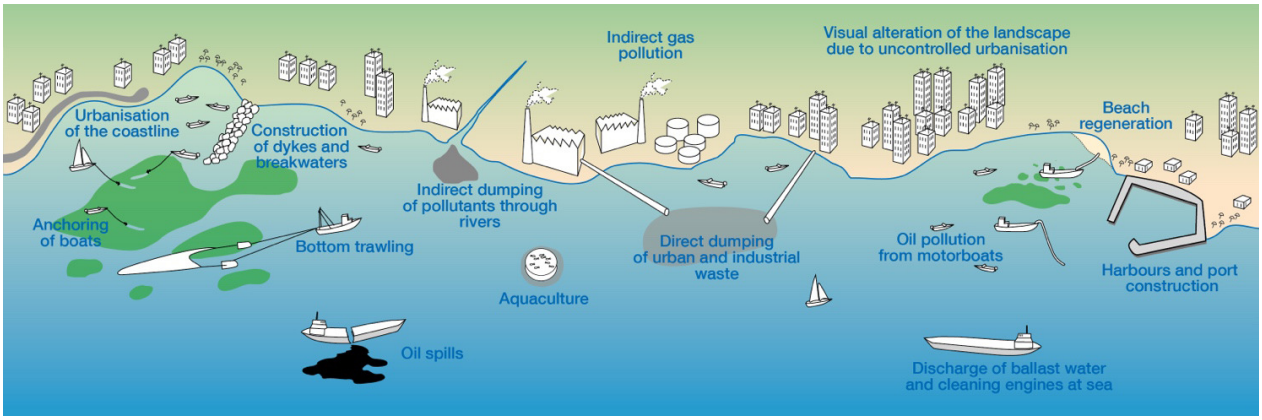


Figure 1. Some of the main anthropogenic pressures in urban marine areas. Notes: The authors were responsible for the translation of this figure; Illustration by Jordi Corbera. Source: Vendrell-Simón et al. (2022).

The coastal city of Barcelona (Catalonia, Spain), in the northwestern Mediterranean, has a deep maritime heritage and its cultural identity is closely tied to the sea. However, it was not until the 1990s, with the Olympic Games, that its once-marginalised seafront was transformed into a public space for recreation, aesthetics, and well-being. Over the past decade, efforts have intensified to strengthen the relationship between citizens and the coast, extending to the seabed, with the goal of reconnecting Barcelona's residents with the sea and its benefits. This vision is pursued through municipal programmes in collaboration with research centres, aiming to enhance urban liveability and resilience in the face of global change—an ongoing challenge for Mediterranean cities.

To support this effort, various OL initiatives have been launched to engage the public and promote a marine scientific culture that strengthens their connection to the sea, encouraging active participation in restoring urban marine ecosystems. In line with OL principles (Cava et al., 2005) and the goals of the UN Ocean Decade (IOC-UNESCO, 2018)—which envisions "an inspiring and engaging ocean where society understands and values the ocean in relation to human well-being and sustainable development" (IOC-UNESCO, 2021)—marine scientists and scuba divers have developed collaborative projects to improve OL among citizens.

Building on these factors, this study outlines the conceptualisation and framework of a marine research project: the Gorgonia Barcelona project. Throughout the process, multiple stakeholders were involved in following a responsible research and innovation (RRI) approach, which will be explained further. Information was gathered on different stakeholder groups, contributing to addressing research knowledge gaps and integrating them into the process in line with recommendations by Lucrezi et al. (2019) regarding divers and Salazar et al. (2024) regarding fishers. This project focuses on urban marine ecosystems, specifically marine benthic ecosystems dominated by the Gorgonian species *Leptogorgia sarmentosa* (Esper, 1791) in Barcelona.

Leptogorgia sarmentosa is a gonochoric Mediterranean Gorgonian species. Although it is known to survive in harsh urban conditions, it is more commonly found in non-harbour environments, usually as isolated colonies (Carpine, 1963; Gatti et al., 2012; Gori et al., 2011; Weinberg, 1976). Its bathymetric range extends from the surface (described by Betti et al., 2018) to depths of 300 metres (Carpine & Grasshoff, 1975). Gorgonians, which are found globally and across a wide range of depths, play a crucial role in marine ecosystems. Due

to their three-dimensional structure, they provide shelter (Ponti et al., 2016) and nursery habitats (Cau et al., 2020), supporting the survival of numerous species and contributing to increased marine biodiversity (Gili & Coma, 1998).

The Mediterranean Sea is often considered a biodiversity "hotspot." Despite representing only 0.32% of the ocean's total volume, it harbours 7%–10% of known marine species (Bianchi & Morri, 2000; Coll et al., 2010). However, there has been a proven rise in climate change impacts on marine benthic ecosystems in the Mediterranean Sea. In addition, some of its ecosystems have been poorly studied, and the associated socio-ecological dimensions are not well understood (Garrabou et al., 2022). On the other hand, marine citizen science has been shown to be an effective approach to fostering citizen engagement in marine research, playing a key role in enhancing conservation and management strategies for a sustainable future (Figuerola-Ferrando et al., 2024).

The study primarily aims: (1) to present the conceptualisation of the collaborative and inclusive initiative and lessons learned after a four-year-long successful implementation of the project—as a case study in Barcelona for citizen engagement in the monitoring of urban marine ecology, particularly focusing on marine benthic organisms dominated by Gorgonians; (2) to contribute to OL priority research areas by providing a Q-sorting tool aligned with OL dimensions to assess divers' perceptions based on their experience in urban marine ecosystems; (3) to shed light on Barcelona's divers' perspectives; (4) to provide insights into the role of fishers in the conservation of urban marine benthic ecosystems in Barcelona; (5) to present additional observations of other stakeholders' involvement in the study of urban marine ecosystems in Barcelona, especially highlighting the role of elderly people in achieving SDGs; and (6) to contribute to a more comprehensive understanding of urban marine ecosystems as well as the role of coastal cities and their governance in fostering inclusive approaches to better promote OL and achieve sustainability goals.

2. Methods

2.1. Study Area

The study area is located in the coastal city of Barcelona, in the northwestern Mediterranean. Specifically, scuba divers identified aggregations of *Leptogorgia sarmentosa* at the outer part of the harbour entrance (coordinates 41°22'N 2°11'E). Consequently, marine benthic ecosystems dominated by *Leptogorgia sarmentosa* in the Gorgonia Barcelona project were monitored at this site (Figure 2). The colonies were found at a depth of approximately 19 metres, growing on a submerged dyke.

The study area is located near Barceloneta, Barcelona's main artificial beach. Several piers have been built in the area to maintain the shoreline, and due to high erosion rates, there is a continuous influx of river sediments, resulting in a seabed composed of fine particles (Tomás-Cubells, 2013). Fishing is prohibited in this area, which minimises the presence of abandoned, lost, or otherwise discarded fishing gear. However, evidence of poaching, such as lost hooks and fragments of fishing lines, was found. Although scuba divers occasionally visited the area, interest in diving increased significantly after the project began in 2021, and the rediscovery of Gorgonians has been widely reported in newspapers and the media. High levels of heavy metals were found in the area in 1991 (Palanques & Diaz, 1994), but this situation has improved considerably thanks to the implementation of policies to improve the quality of Barcelona's seawater and

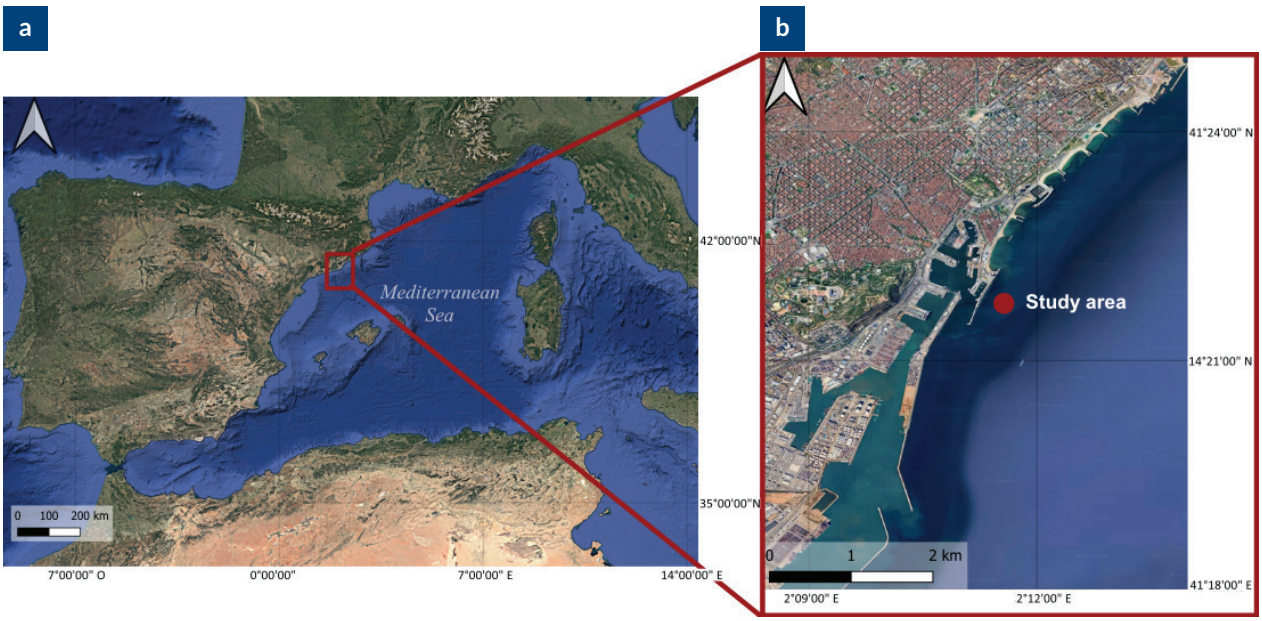


Figure 2. The study area is located in the northwestern Mediterranean, off the coast of Barcelona, where marine benthic ecosystems dominated by *Leptogorgia sarmentosa* are monitored in the framework of the Gorgonia Barcelona project: (a) A map showing the northwestern Mediterranean basin, where the city of Barcelona is located; (b) enlarged view of the study area for monitoring the Gorgonians of the Gorgonia Barcelona project, at the outer entrance of Barcelona's Olympic harbour.

sediments. Nevertheless, the area still received a "black flag" in the 2022 annual report from the Spanish grassroots environmental group Ecologistas en Acción, mainly due to hydrocarbons and heavy metals derived from the heavy maritime traffic associated with the nearby harbour of Barcelona—discharges from industrial and urban sources that are not adequately treated, microplastics from human activity, and atmospheric emissions from ship combustion and port machinery (Ecologistas en Acción, 2022).

2.2. The Gorgonia Barcelona Project Conceptualisation

When a scuba diver from the Catalan Federation of Subaquatic Activities (FECDAS) reported in 2020 the sighting of dense aggregations of *Leptogorgia sarmentosa* in Barcelona's waters, a research group at the Institut de Ciències del Mar from the Spanish National Research Council (ICM-CSIC), aware of the importance of the finding, decided to prospect the area. Thanks to the technical support provided by FECDAS, this prospecting was carried out. After confirming the high ecological importance of the finding, and thanks to the support and recommendations received by sociologists and marine researchers participating in the ResBios project (ResBios, 2022), the Gorgonia Barcelona project soon emerged.

The ICM-CSIC, the leader of this project, always with the technical support of FECDAS, was one of the partners participating in the European Horizon 2020 project ResBios. The project was part of the Science With and For Society programme and was based on the RRI framework. RRI seeks to manage research and innovation by engaging a wide range of stakeholders and the public from the outset of the process. This inclusive approach aims to foresee the positive impacts of research and innovation on society while minimising potential risks. The concept of RRI has been explored through several key dimensions, such as inclusion, anticipation, responsiveness, reflexivity, sustainability, and care (Burget et al., 2017).

Although it had some prior experience in this area, the ICM-CSIC participated in the project as an institution still in the early stages of integrating RRI practices. As such, it was accompanied by more experienced partners who had participated in the previous StarBios project (StarBios, n.d.), which followed a similar approach. During the project, the ICM-CSIC worked on different so-called "grounding actions" (specific actions conducted in less-experienced RRI institutions, with the final goal of integrating RRI into their daily procedures), with a special focus on three key aspects of RRI (gender equality, citizen engagement, and scientific education; Salazar et al., 2022a). The specific definitions of the key RRI concepts worked throughout the project are shown in Figure 3.

Since the conception of the Gorgonia Barcelona project and following the instructions of the sociologists involved in the ResBios project, the participation of citizens in the project was enhanced, and continued well after the project had finished, following the Manifesto for the Transformation of Science-Society Relations (Bijker et al., 2022). The name of the project (Gorgonia Barcelona) was voted on by more than 50 participants of an OL workshop organised at the ICM-CSIC as part of the Biennial of Barcelona. The project involved participants from the four sectors of the quadruple helix: academia, industry, government, and civil society (Roman et al., 2020). This concept (quadruple helix) soon evolved into the quintuple helix incorporating the natural environment and pursued the achievement of SDGs (UN, 2015), especially SDG 14 "life below water," SDG 11 "sustainable cities and communities," and SDG 17 "partnerships for the goals." Different indicators were also set for following up on the initiative (Schmidt,

Figure 3. The key aspects of RRI were addressed through grounding actions by research organisations in the ResBios project. Notes: The figure outlines the key aspects of RRI integrated into the ResBios project through concrete actions carried out by the research organisations; definitions for each concept are provided to ensure clarity and prevent potential misunderstandings. Source: ResBios (2022).

2023). The project was also developed under the umbrella of the local initiative Espai Mediterrani (Espai Mediterrani, 2020), where the ICM-CSIC participates together with other neighbourhood associations in pursuing the same goals of promoting OL, social justice, sustainability, and ocean health. The project followed a "local-to-global" approach and secured financial support from Barcelona City Hall and local businesses. The project was launched in 2021 in parallel with the global efforts of the UN Ocean Decade (IOC-UNESCO, 2018). Accordingly, it has been developed following the recommendations of the OL outcomes and challenges, as well as recommendations for climate action within the UN 2030 Agenda (Soergel et al., 2021). Soon after, it also followed an alignment with global OL efforts, such as the OL dimensions proposed by McKinley et al. (2023). The conceptualisation phase of the project included the following steps: stakeholder mapping and engagement, urban marine ecosystem assessment, OL framework integration, exchange of knowledge and perceptions with stakeholders involved, and communication and outreach strategy. The Gorgonia Barcelona project was structured in this way to contribute to knowledge gaps in urban marine ecology, promoting stakeholder-driven conservation efforts and serving as a model for inclusive marine research in urban environments.

2.3. Q-Sort Study, Divers, Fishers, and Other Stakeholders Involved

Given that the project emerged from an alliance between scuba divers and marine scientists, and considering the strong engagement of scuba diving volunteers, a study was conducted to explore divers' perceptions of Barcelona's urban marine ecosystems, based on OL dimensions (McKinley et al., 2023). The chosen methodology was the Q-method, following the recommendations of Webler et al. (2009). A Q-sorting method was designed, and 13 statements were produced, covering the main OL dimensions (McKinley et al., 2023), as shown in Table 1. For some of the OL dimensions, there was more than one statement (two for communication, one as a receiver, and another as a transmitter) and three for emotional connections (one positive, one negative, and another more neutral). Responses concerning different types of emotions were sought, to investigate if there was an emotional disconnection with the ocean when they perceived an impact. The first six statements concerned Barcelona's marine users in general, defined as individuals who perform activities regularly in Barcelona's marine and/or maritime areas or nearby. The last seven were related to the participants (divers) themselves, to better reflect their perceptions of the marine environment.

Following the recommendations of the ICM-CSIC Ethics Committee on ethical considerations and data protection (Ministerio de la Presidencia, Justicia Y Relaciones con las Cortes, 2018), an interview was conducted with the participants. The study was conducted with all the divers who participated in the project, including those who came only once and those who regularly participated in it. The interviews were conducted in person or virtually, depending on the availability of the volunteers. During the interviews, the scuba divers provided personal data and were invited to participate in the Q-test (Table 1 and Figure 4). Any doubts regarding the statements were addressed and clarifications were provided to ensure that all participants understood the questions in the same way. Qualitative data were also compiled to better contextualise the answers provided. The criterion to participate in this study was being a scuba diver who had participated in the field sampling of the Gorgonia Barcelona project. Volunteers were also asked to fill in some demographic information, as well as data about their use of marine ecosystems. Then, they were asked to fill in a pyramid with the 13 statements provided in Table 1. In this pyramid, there were gaps given on a scale from "strongly agree" to "strongly disagree," and they could only fill each gap with one statement (Figure 4).

Table 1. Statements of the Q-test conducted with divers of Barcelona about their perceptions and experiences as sea users in Barcelona and their related OL dimensions.

About your viewpoint on the users of the sea in Barcelona (including divers and other users)	
Statement	OL dimension covered
1. They have sufficient knowledge about Barcelona's marine ecosystems to act responsibly and make informed decisions	Knowledge
2. They are always kept informed by the authorities about risks or issues related to the marine environment that could negatively impact them, allowing them to decide how to act	Trust and transparency
3. They can meaningfully participate in decision-making processes that affect Barcelona's marine environment	Communication
4. They can easily empathise with other types of users because there are various tools available to explain and/or simulate these experiences	Access and experience
5. They generally share their observations of the marine environment—both positive and negative—within their personal networks	Communication
6. They have easy and sufficient access to scientific knowledge about Barcelona's marine environment and can contribute to generating more	Awareness
About your own experience as a user (diver) of the sea in Barcelona	
Statement	OL dimension covered
7. In general, Barcelona's marine ecosystems are not in good conservation status and do not have adequate protection measures	Attitude
8. I report or notify the relevant authorities when I detect a phenomenon that I consider abnormal, which could indicate an environmental alert or be of scientific interest	Behaviour
9. I consider myself a marine activist	Activism
10. My mood is not affected by the "health status" of the sea	Emotional connections
11. I understand the environmental changes associated with an urban ecosystem and adapt to them easily	Adaptive capacity
12. I feel positive emotions when I think about Barcelona's marine environment	Emotional connections
13. I feel negative emotions when I think about Barcelona's marine environment	Emotional connections

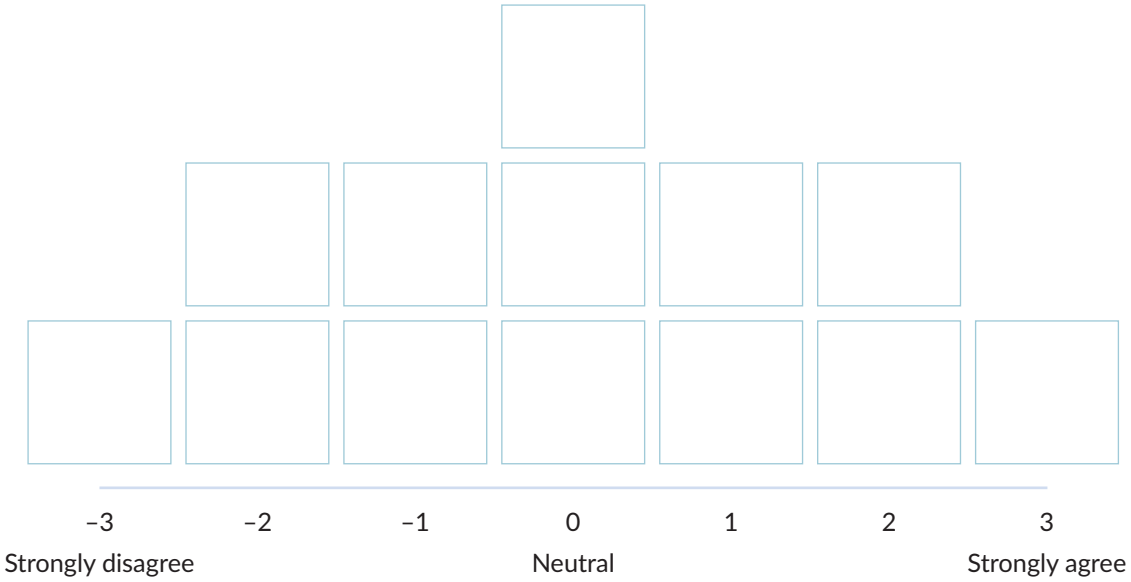


Figure 4. "Pyramid" used for the Q-sorting conducted with scuba divers. Note: Participants were instructed to place each of the 13 statements into one of the 13 available slots, ensuring that no more than one statement occupied the same slot.

2.4. Gathering Fisher's Perspectives in Barcelona's Urban Marine Ecosystems

Fishers are other relevant marine stakeholders that should be involved in managing marine ecosystems if we want to improve the management, preservation, and conservation of a certain area. The exploitation of living and non-living resources is one of the three primary drivers of marine urbanisation, as described by Todd et al. (2019; the other two are pollution and modification of natural habitats). Fishers play an important role in this regard. Previous studies have highlighted the crucial role of fishers in conservation efforts and the importance of exchanging perspectives while valuing their local ecological knowledge, as shown by Aswani et al. (2018), particularly in areas near Barcelona, such as the Cap de Creus marine protected area (Biel-Cabanelas et al., 2023; Salazar et al., 2024; Santín et al., 2022). Thanks to the contact with fishers through the Espai Mediterrani initiative, an initial meeting was conducted with a Barcelona fisher to exchange points of view and perceptions of Barcelona's urban marine ecosystems and to collect input and feedback for marine conservation goals.

2.5. Collecting Feedback From Citizen Engagement With the Project

In addition to the above-mentioned studies and the perspectives collected from different stakeholders involved in the Gorgonia Barcelona project, further insights into OL were collected from other groups that participated in related education and outreach activities. In the workshop held after the Spanish lockdown period due to the Covid-19 crisis, during which the name of the project was decided, a simple test for collecting impressions about OL promotion was also shared.

3. Results

3.1. The Gorgonia Barcelona Project

This project has been successfully conducted since its inception in 2021. Several stakeholders were involved in the project in various ways. It was designed to be inclusive, enabling broad participation. With this in mind, it included activities both within the urban marine ecosystems (Figure 5) and at the marine research institution, as well as at other locations. Participants also had the option to join these activities online or watch the recorded sessions offline later (Figure 6). Activities in the field were organised in coordination with FECDAS, who provided technical and logistical support and helped to recruit volunteers for each of the monthly samplings. In each of them, a briefing was provided promoting OL and explaining the protocols of the programmed activities for the sampling day. Additionally, the project made it possible to conduct pilot restoration actions both in the inside and outside areas of the harbour entrance and further monitoring of both areas (employing a remotely operated vehicle in the area inside the harbour). It is important to mention that scuba divers were extremely concerned about the wet wipes that were found suffocating Gorgonian polyps. Consequently, they produced awareness materials for social media and provided them to marine researchers for further dissemination and awareness purposes.

Different education and outreach initiatives were also promoted during the project. In each activity, including the FECDAS briefings, there was a dissemination of the importance of the conservation of urban marine ecosystems and benthic ecosystems dominated by Gorgonians. The crucial role of OL and the need to develop sustainable attitudes and behaviour were also stressed. The project raised the attention of different TV channels and social media, and it was also shared in different scientific conferences and meetings, being present in both local and global initiatives, such as the International Coral Reef Symposium (Salazar et al., 2022b).

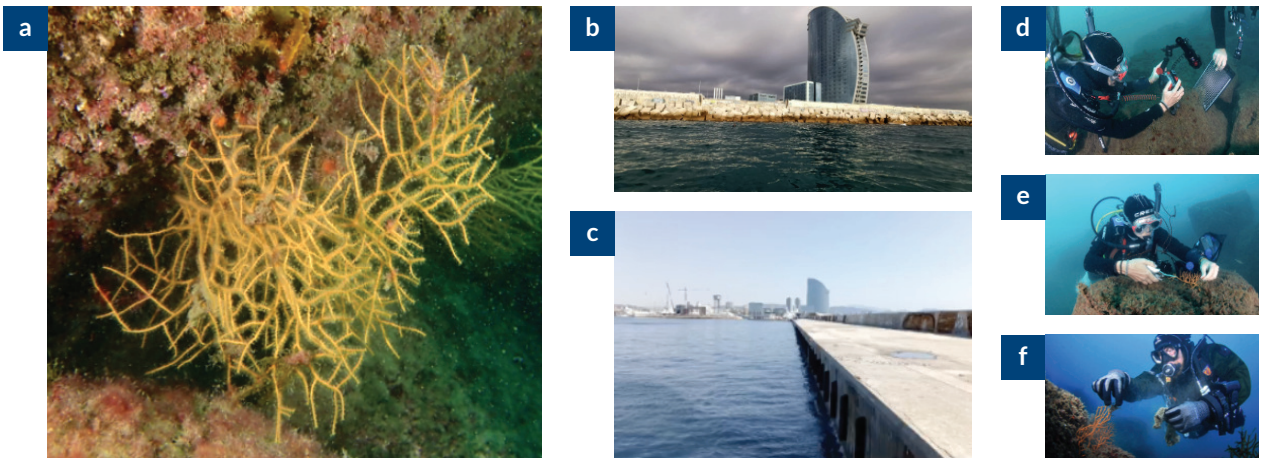


Figure 5. Overview of the actions conducted in the field: (a) The study species *Leptogorgia sarmentosa* in the study area (Photo by Susana Garrido); (b) and (c) Views of the exterior (study area) and interior sections of the harbour entrance, with the harbour visible, providing context for the surrounding environment of the study area; (c) the project also facilitated Gorgonian restoration pilot actions using technical diving and remotely operated vehicles in the interior section; monitoring activities such as photographing (d), collecting samples (e), and reporting and removing wet wipes (f).

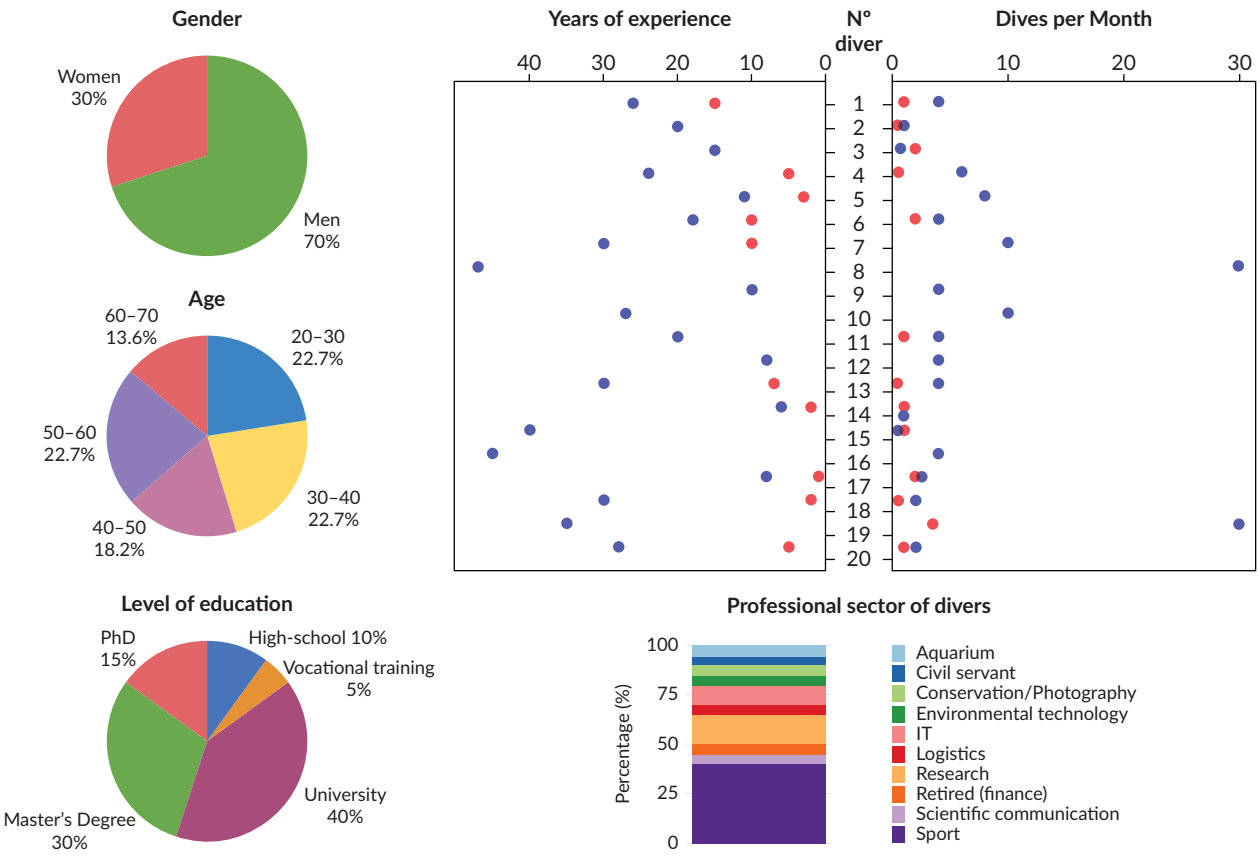
Figure 6. Some of the engagement activities developed in the framework of the Gorgonia Barcelona project included: visits to learn about Gorgonians (a), which included feeding them (e), development of final master's degree research works in collaboration with universities (b), secondary school scientific projects (c), and meetings and workshops involving citizens of diverse ages, social backgrounds, and sectors (d).

The case study of Barcelona is very similar to the one reported by Betti et al. (2018) in Genoa (Italy). Consequently, the science conducted in the project involved collaboration with other local research groups from Barcelona, as well as international collaborations with research institutions from Italy, France, and the US to provide data spanning from the local to the global context. Within the framework of the project, it has been possible to conduct scientific studies on Gorgonian reproduction, metabolism, resistance to thermal stress, microbiome, and transcriptome. These studies are still ongoing.

3.2. Divers' Perceptions

In total, 20 scuba divers who participated in the project sampling answered the test. The summary of the results is shown in Figure 7.

The participants included 6 women and 14 men. Their ages were as follows: five between 20 and 30 years, five between 30 and 40, four between 40 and 50, five between 50 and 60, and three between 60 and 70. Two had studied until secondary school, one had undergone vocational training, eight had undergraduate degrees, six held a master's degree, and three held a PhD. Regarding their professions, eight were related to sports, three to research, development, and innovation, one to logistics, two to IT, one worked in the administration, another was retired but had worked in the financial sector, one worked in an environmental agency, one was a photographer, another in scientific communication, and another in an aquarium. All of them had more than six years of diving experience, which ranged from 6 to 45 years (specifically in Barcelona, this experience ranged from 1 to 45 years). Their frequency of practising snorkel or scuba diving ranged from daily to five times per year in general, and from one day per week until one day per year. Seventeen of them lived or had lived in Barcelona, while three had not. Sixteen currently lived in a coastal city or village, whilst four did not. When asked about where they acquired marine knowledge, sources varied



Mostly agree with: 7. In general, Barcelona's marine ecosystems are not in good conservation status and do not have adequate protection measures.
Mostly disagree with: 1. Barcelona marine users have sufficient knowledge about Barcelona's marine ecosystems to act responsibly and make informed decisions.
Ranking and total marks given (in parenthesis) to each of the statements
9. I consider myself a marine activist (25).
5. Barcelona marine users generally share their observations of the marine environment—both positive and negative—within their personal networks (23).
7. In general, Barcelona's marine ecosystems are not in a good conservation status and do not have adequate protection measures (14).
11. I understand the environmental changes associated with an urban ecosystem and adapt to them easily (14).
12. I feel positive emotions when I think about Barcelona's marine environment (13).
8. I report or notify the relevant authorities when I detect a phenomenon that I consider abnormal, which could indicate an environmental alert or be of scientific interest (11).
6. Barcelona marine users have easy and sufficient access to scientific knowledge about Barcelona's marine environment and can contribute to generating more (7).
13. I feel negative emotions when I think about Barcelona's marine environment (–3).
10. My mood is not affected by the "health status" of the sea (–7).
4. Barcelona marine users can easily empathize with other type of users because there are various tools available to explain and/or simulate these experiences (–9).
2. Barcelona marine users are always kept informed by the authorities about risks or issues related to the marine environment that could negatively impact them, allowing them to decide how to act (–17).
3. Barcelona marine users can meaningfully participate in decision-making processes that affect Barcelona's marine environment (–25).
1. Barcelona marine users have sufficient knowledge about Barcelona's marine ecosystems to act responsibly and make informed decisions (–32).

Figure 7. Summary of answers given by scuba divers who participated in the project and the study. Note: In the scatterplot, blue dots represent "in general," and when the answer is different for Barcelona, it is represented by red dots.

from personal experiences to books, guides, documentaries, talks with fishers, talks with marine scientists, talks with other scuba divers, involvement in citizen science initiatives or scientific courses, university studies, social media, scuba diving courses, and underwater photography competitions. When asked about their perception of their marine scientific knowledge, all of them voted at least 6 out of 10, with most of the

results 7 or 8 (in this item, 5 was considered as sufficient knowledge). Surprisingly, respondents who had higher studies in marine-related fields were not necessarily those who gave themselves higher marks.

Volunteers assigned the highest value (+3) to statements 1–2 and 5–12. Four people assigned the highest value to statement 7, three to statement 9, three to statement 5, two to statement 11, two to statement 12, two to statement 8, and one for each of the following statements: 1, 2, 6, and 10. Despite differing opinions, scuba divers as individuals agreed more with the fact that marine ecosystems in Barcelona were not in a good health status and/or had inadequate protection. They also agreed to consider themselves marine activists and promoters of OL through their own experiences. They reported interesting sightings during their activities and had positive emotions when thinking about the marine ecosystems in Barcelona. Also, they understood the associated changes to urban marine ecosystems like Barcelona's (in uses, modification of the coastline, etc.)

Volunteers assigned the lowest value (−3) to statements: 1–3, 6–8, and 10–12. Five people assigned the lowest value to statement 1, three to statement 13, three to statement 3, two to statement 10, two to statement 2, and one for each of the following statements: 6–8, 11, and 12. Despite differing opinions, scuba divers as individuals disagreed more with the fact that Barcelona's marine users have enough knowledge to be able to act in a responsible and sustainable way. In addition, three strongly disagreed with having negative emotions when thinking about Barcelona's marine ecosystems and three strongly disagreed with having enough opportunities to participate significantly in decision-making processes with repercussions for Barcelona's marine ecosystems. Furthermore, they strongly disagree with being always informed by authorities about the risks or problems associated with Barcelona's marine environments. Finally, one strongly disagreed with the fact that his mood was not related to the ocean health status of Barcelona's marine ecosystems.

When looking at the total marks given, the most voted statement was "I consider myself a marine activist," with 25 points given, followed by 23 points given to statement 5 (they consider themselves as promoters of OL). The statement related to adaptive capacity received 14 points, followed by having positive emotions when thinking about Barcelona's marine ecosystems (13 points), then 11 points given to statement 8 (reporting special sightings while diving), and seven to statement 6 (they have enough access to marine scientific knowledge). Statements 13 (negative emotions, −3), 10 (mood not altered by Barcelona's marine ecosystems ocean health, −7), 4 (can empathise with other Barcelona marine users, −9), 2 (are always informed by the authorities about risks associated with marine ecosystems, −17), 3 (they have the opportunity to participate in decision-making related to Barcelona's marine ecosystems, −25), and 1 (Barcelona's marine users have enough knowledge to behave sustainably, −32) gained negative overall marks, reflecting a strong disagreement with these statements.

A parallel analysis conducted using R software (R Core Team, 2023) did not identify any significant factors in the data per se. However, an exploratory factor analysis extracting three factors with a maximum variation rotation "varimax," yielded a mean item complexity of 1.5 and revealed that three factors were sufficient to account for the observed variance. A factorial loading matrix was used to show how and to what extent each observed variable (in this case, each statement) was associated with each latent factor. It provided three main types of respondents (Figure 8). The first type of scuba divers believe that authorities do not adequately inform Barcelona's marine users, that Barcelona's marine ecosystems are in bad health and not sufficiently protected, and they do not express strong positive emotions towards Barcelona's ecosystems compared with

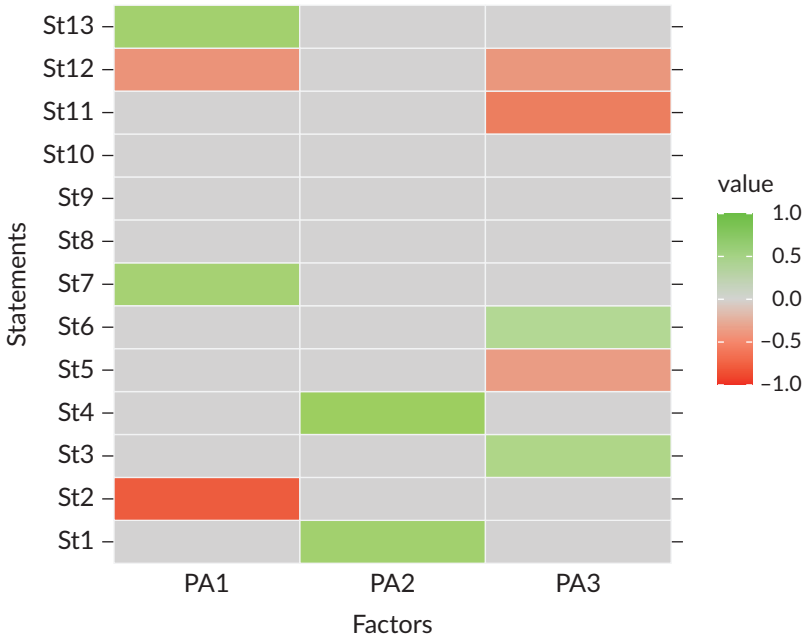


Figure 8. Factorial loading heatmap from the Q-test conducted with scuba divers in Barcelona. Notes: The colour scale represents the strength and direction of the values: green for positive values, red for negative values, and light grey for near-zero loadings; PA1 (first principal axis factor), PA2 (second principal axis factor), and PA3 (third principal axis factor) refer to each of the three main factors identified; note that there is only one statement (statement 12) that is common to factors 1 and 3, the other statements are unique for each of the factors.

the others (in fact, they show negative emotions). The second group of respondents exhibits a more positive outlook: they believe that users of Barcelona's marine areas have enough knowledge and can behave in a more sustainable way. They can also empathise with other users. The third group believes that they can participate in decision-making, that they contribute little to promoting OL, and that although they have enough access to marine knowledge, they have difficulties in understanding changes in Barcelona's marine areas, and they do not show positive emotions towards Barcelona's marine ecosystems.

In general, the first factor (which can be referred to as "negative") accounts for 17.8% of the variance in responses, the second factor (which could be referred to as "positive") explains 12% of the total variance, while the third factor (labelled "neutral") explains 11.5% of the total variance. Altogether, 41.3% of the total variance could be explained by the three factors extracted. Regarding clarity criteria, 10 statements were related to these factors (St1–St7, St11, St12, and St13) and three did not have an associated factor (St8–St10).

3.3. Fishers' Perspectives

The main inputs provided by the fishers were as follows:

1. Barcelona's fishers felt demonised by several stakeholders. They recognised that their fishing activities have an impact on marine ecosystems and were aware of these impacts. However, they argued that it is unfair to single out their sector as the sole contributor to marine environmental issues. They also believed that the term "overfishing" was overused.

2. In the same vein, fishers advocated for identifying other significant environmental impacts, such as the source of the large quantities of wet wipes and other debris frequently caught in their nets—debris that they believe has a severe negative impact on marine ecosystems.
3. Fishers expressed a desire for a more horizontal and reciprocal exchange of information. They emphasised that they were not resistant to change and had already implemented all the adjustments recommended by the administration. However, they pointed out that in past collaborations with biologists, there was often no feedback or follow-up after they provided data, which left them feeling overlooked and disrespected. This lack of recognition has contributed to their reluctance to participate in similar initiatives.
4. Fishers highlighted their extensive local ecological knowledge, citing, for instance, specific rocky areas where bottom trawling is not conducted and which they believe are well preserved, but, according to them, remain unstudied by scientists. Additionally, based on their daily fishing activities, they observed changes in marine ecosystems and expressed concern over the impact of pesticides and dissolved pollutants, which they felt had not been sufficiently addressed.
5. Fishers felt unheard and insufficiently integrated into decision-making processes. Fishers argued that they are often excluded from decisions that directly affect their sector and called for greater transparency, trust and compensation when more sustainable measures are implemented or when they participate in sustainability projects that impact their work. They emphasised that their cooperation should not be taken for granted or exploited, particularly when these initiatives further strain an already demanding profession.

In this regard, the importance of establishing common goals was highlighted, with both biologists and fishers agreeing on the need for compensated fishing ban periods and the implementation of mitigation measures that could yield benefits for both marine conservation and the fishing industry.

3.4. Learnings From Other Stakeholders Involved

Fifty-six participants rated their marine scientific knowledge at 2.71/5, and there was a consensus on the desire for more education and outreach opportunities to increase OL levels. The most expressed preference for the frequency of such events was once a month. When asked about their perception of ocean health in Barcelona, participants always gave less than 3/5, sometimes giving a 2 or a 1. In terms of biodiversity, they usually gave 3/5, although some of them gave 2/5 and 4/5. In general, teachers and educators knew that Gorgonians were animals, but the public and children did not usually know this.

One of the education and outreach experiences conducted within the framework of the project was a request from an intergenerational service-learning initiative led by a vocational training programme. The project aimed to connect elderly people in the Barceloneta neighbourhood with vocational training students to explore challenges related to the climate emergency. The students expressed interest in visiting the ICM-CSIC, where one of the projects presented to them during the visit was the Gorgonia Barcelona Project. One of the main conclusions from this exchange was that young people felt a strong sense of responsibility but lacked the necessary tools to counteract climate trends. Meanwhile, although elderly participants often felt excluded from the conversation and believed they lacked sufficient knowledge, it was collectively concluded that they could play a crucial role in addressing the climate crisis. By sharing their experiences of a simpler and humbler lifestyle from their childhood, adolescence and youth, they could help promote more sustainable behaviours.

Regarding the exchange of perspectives with policymakers and administration, it is important to highlight that the project was very well received and supported. Policymakers and administrators valued having interlocutors to discuss marine benthic ecosystems and recognised the project as an inspiration for achieving climate mitigation goals.

Additionally, the private sector expressed interest in financially supporting the project and becoming directly involved, for example, through activities such as diving, visiting aquaria, and feeding Gorgonians.

4. Discussion

4.1. Collaborative and Inclusive Citizen Engagement Initiatives in Coastal Cities

Coastal environments in urbanised areas are often degraded due to pollution and other negative impacts from human activities (Islam & Tanaka, 2004). This fact contrasts with the observations made by divers in the harbour area of Barcelona, with a high diversity and a surprising population of Gorgonians. It is known that urban infrastructures, such as docks or harbours, have a positive effect on the creation of habitats and the increase in biodiversity (Chapman & Underwood, 2011). But what was observed in Barcelona was unexpected and this promoted the inception of the Gorgonia Barcelona project. The project has been developed by posing a series of ecological questions that have always been shared with the participating social groups. In this way, the volunteers who participated were aware that they were taking part in a scientifically compelling project, which made it easier for them to connect with it emotionally. Thus, communication and OL between scientists and citizens were facilitated. Another important aspect of the project was the fact that it was developed in an urban setting, particularly in a large city like Barcelona. This fact makes it easier for many groups or citizens who wish to get involved in marine research projects to do so due to the proximity to their area of residence. Not everyone can travel to locations far from their city, regardless of how interesting the research projects may be. Therefore, projects conducted in urban areas hold great potential for reaching a wider range of social groups and increasing OL.

As this was the first initiative of its kind—making it both the initial monitoring of Barcelona's Gorgonians and the launch on this context of a new project guided by RRI—its main objective was to serve as a pilot. The goal was to explore the feasibility of conducting regular samplings with scuba diving volunteers in Barcelona's urban marine ecosystems, assess how the public and various city stakeholders would respond, and test a new model for citizen engagement in coastal cities. Despite the project already aligning with most of the 10 principles of citizen science, it could still be better aligned with them (Robinson et al., 2018), especially with those related to generating new open-access data. These aspects will be further explored in the future.

4.2. Gathering Divers' Alignment With OL Dimensions

The sex ratio of divers involved in the study in Barcelona (Catalonia, Spain) corresponds to similar data reported by Lucrezi et al. (2019) in Portofino (Italy) and differs from the data reported by divers from Mozambique, where there was a more equal representation of men and women (Lucrezi & Saayman, 2017). This reflects the general predominance of males in diving in Barcelona. It is important to mention that this issue was already identified by FECDAS, which participates in several programmes to reverse these trends and promote diving activities among women. As highlighted by Cerrano et al. (2017), it is very important to characterise diverse

communities because they often incorporate different perspectives and opinions that could not be considered universal. Surprisingly, respondents who had higher studies in marine-related fields were not necessarily those who gave themselves higher marks. This is likely because people who work directly in marine science are also aware of the wide range of knowledge encompassed within the field and so are more aware of their knowledge gaps. Other factors that were not extracted, or complementary studies, could help to better interpret the answers given. However, with the current analysis, we can already gain insight into the varied perceptions of each scuba diver. The divers from Barcelona were not an exception in that regard, and the result of the study conducted reflects diverse opinions among them, aligned with findings by Lucrezi et al. (2019) when analysing divers from Italy and Mozambique. Nevertheless, as most of the results can be explained with the three identified factors, the Q-sorting tool presented here could be a new tool that provides a solution to address these assessments, while also contributing to building further knowledge about the relationship of divers with the OL dimensions.

4.3. Adding Barcelona Fishers' Perspectives in OL Conversation

Addressing the needs of the involved stakeholders and setting OL strategies for decision-making, based on scientific marine knowledge, is crucial for managing urban marine ecosystems, particularly regarding the fishing sector. This approach aligns with findings from other, less impacted areas (Salazar et al., 2024). When this study was conducted, fishers were not involved in the Gorgonia Barcelona project, but thanks to further conversations, they will participate by providing Gorgonians caught in their nets, following previous similar approaches reported by Montseny et al. (2021) that ensure sustainable and feasible ways of conducting restoration actions. Additionally, responding to their concerns about wet wipes and local ecological knowledge not collected, researchers involved in the project will move on to provide answers to these concerns, following successful results, considering that this practice of responding to fishers' needs contributes to generating trust and transparency to build a strong and collaborative relationship among scientists and fishers, as reported by Biel-Cabanelas et al. (2023).

4.4. Final Remarks and Recommendations for the Governance of Urban Marine Ecosystems

As mentioned in Section 4.1, marine research projects conducted in urban areas following inclusive and collaborative approaches hold great potential for reaching a wider range of social groups and increasing OL. This is especially important to be considered for governance purposes in urban marine areas, as several groups have highlighted that they often feel excluded from the conversation. For coastal cities to have citizens committed to sustainable and climate action, they must be empowered and appreciated as stewards of their urban marine ecosystems. Important efforts have already been made in "green areas" (Magrinya et al., 2023) that could be extended to "blue areas."

5. Conclusions

This study highlighted several key aspects regarding the involvement of various stakeholders in Barcelona's urban marine ecosystems, particularly in the context of the study of marine benthic ecosystems dominated by Gorgonians. The insights gained offer a model for other marine conservation efforts focused on flagship species in different regions and can contribute to understanding how to engage different stakeholders in achieving conservation and OL objectives. The study emphasises the importance of participatory and

collaborative models to align efforts and goals across diverse sectors, contributing to OL global efforts and fostering more sustainable behaviour, closer relationships, and the stewardship of urban marine ecosystems. Combining both top-down and bottom-up approaches has been proven to be an effective strategy for marine protected area planning worldwide (Gaymer et al., 2014). These recommendations should also be applied to often-overlooked marine areas such as urban marine ecosystems. This study aimed to shed light on this issue and, as a suggested improvement, when applied in other areas, it should be recommended to better align with the 10 citizen engagement principles (Robinson et al., 2018). From the study, the following final key conclusions can be drawn:

- Divers: The Q-test conducted with Barcelona's divers reveals diverse profiles within the group, each offering unique insights into the city's urban marine ecosystems. Their direct interaction with underwater environments provides valuable perspectives that can enhance and complement scientific research, helping to fill knowledge gaps in data collection and monitoring. By involving divers as citizen scientists, their observations and expertise become a vital resource for advancing urban conservation efforts. The results of the Q-test suggest that, overall, scuba divers in Barcelona play a key role in promoting OL, a finding consistent with previous studies by Chung et al. (2013) and Lucrezi et al. (2018). Furthermore, the Q-sort emerges as a proven tool that addresses one of the priorities highlighted by Shellock et al. (2024), the need to develop appropriate methods and measures to address OL dimensions, especially emoceans, trust, and transparency. This tool could be used with other groups of divers in Barcelona or other nearby or distant locations, to conduct comparative studies that help to better understand the potential role of divers. The tool could be further explored and potentially adapted for studies with other stakeholders involved in OL promotion.
- Fishers: Fishers are another crucial group in urban marine ecosystems, and their involvement must be prioritised. Consistent with previous research by Salazar et al. (2024) and Montseny et al. (2021), it is evident from the perceptions of Barcelona's fishers that greater efforts are needed to actively engage them in conservation initiatives. This would promote bilateral exchange of information and emphasise the importance of local ecological knowledge, as reported by Johannes et al. (2000). By fostering open communication and integrating the knowledge of both scientists and fishers, we can build stronger partnerships and reduce potential reluctance or conflicts. Sustainable measures implemented by fishers, particularly those in artisanal fisheries, should receive greater recognition and be more actively integrated into management processes, as highlighted by Gómez et al. (2006) and Gómez and Lloret (2017).
- Citizenship: The study underscores the importance of reviving and valuing the knowledge and practices of older generations. Their traditions, often rooted in sustainable practices and a deeper respect for nature, can serve as a foundation for shaping modern conservation strategies. By integrating these perspectives into educational and community initiatives, we can foster a sense of cultural continuity while addressing contemporary ecological challenges.
- Policymakers: Collaboration between scientists, policymakers, and other stakeholders should be based on trust, transparency, and a clear focus on shared goals. Policymakers play a central role in creating the regulatory frameworks and funding opportunities necessary to support participatory models and ensure long-term ecological sustainability.
- Industry: The private sector and industry could provide financial support and actively participate in urban marine ecology studies. Their involvement would help promote more sustainable practices within their companies and contribute to increasing OL.

In conclusion, the study underscores the need for collaborative and inclusive approaches to urban marine conservation, in line with findings from Sauer et al. (2021). The RRI approach, involving participants from the sectors of the innovation quintuple helix, has proven effective in enhancing OL opportunities in marine ecology studies, consistent with previous findings by Lundquist and Granek (2005) and Magoni et al. (2018). Figure 9 presents an adapted innovation model based on the innovation quintuple helix, incorporating key considerations for achieving conservation goals in urban marine ecosystems.

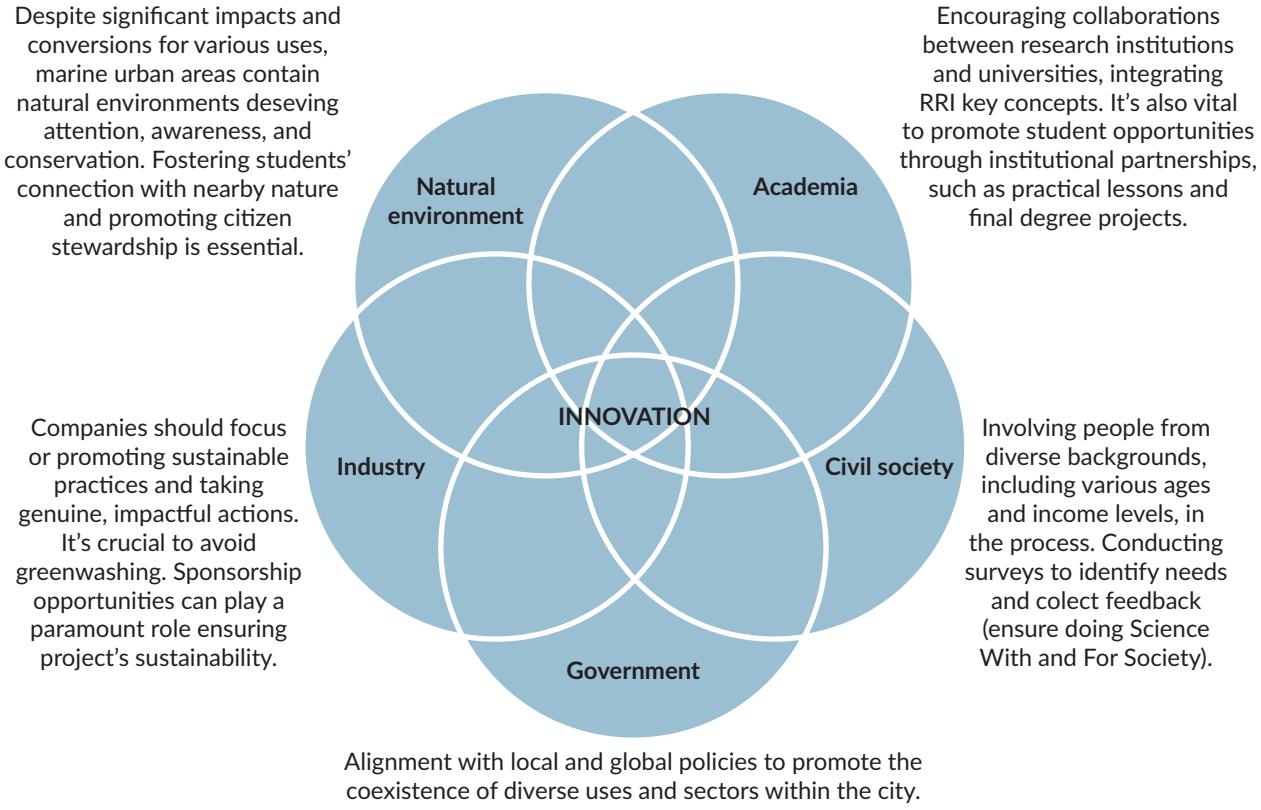


Figure 9. The quintuple helix model adapted to the context of urban marine ecosystems, highlighting key findings and factors that enhance citizen engagement and promote sustainable behaviour in collaborative urban marine conservation initiatives.

Expanding participatory models and advancing OL in coastal cities worldwide will be essential for ensuring the long-term health and sustainability of these vital ecosystems. This study contributes to filling some of the knowledge gaps raised by Shellock et al. (2024) regarding OL research in achieving sustainable ocean futures. The conclusions align with findings about governance approaches that embrace the multidisciplinary and intersectoral nature of OL. The conclusions of this study will serve as a step forward, especially for researchers, practitioners, and decision-makers in Barcelona for promoting OL, but also could be an example for OL multidisciplinary studies and models of governance in other locations. Following these approaches can lead to sustainable and equitable governance and conservation of marine urban ecosystems, supporting broader goals of sustainable development.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

All data collected have been presented throughout the study; for any related enquiries, please contact the corresponding author.

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ARTICLE

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Designing With an Ocean Literacy Approach: Towards the Definition of "Ocean Cycle-Centric Design"

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Abstract

The Ocean Decade has provided a unique framework for fostering science-informed practices that necessitate a rethinking of human relationships with the sea. The 2024 UNESCO *Venice Declaration for Ocean Literacy in Action* highlights the need to develop "ocean-centric design." While the environment-centred design is well-established, the ocean-centric design remains underexplored, particularly regarding its epistemological foundations. This article defines ocean-centric design as an approach to expanding ocean literacy dimensions and driving change across disciplines. Integrating design methodologies (civic design method) and concepts like bodies of water, Hydrocene, and perspectives from the blue humanities, the study proposes a framework and devises indicators to help designers ensure their practices are ocean-centric. These indicators aim to foster a stronger connection with the ocean among society while addressing the Ocean Decade's Challenge 10 "restoring society's relationship with the ocean." To validate these indicators, they are applied to a selection of ocean-design case studies to assess whether the designs are inherently ocean cycle-centric or merely contextualised within an ocean setting. Ultimately, the article seeks to expand the scope of environment-centred design by introducing and emphasising a blue epistemology. The article introduces ocean cycle-centric design, expanding environment-centred design and integrating ocean literacy into resilient design practices for a restored human-ocean nexus.

Keywords

civic design; human-ocean nexus; ocean citizenship; ocean cycle-centric design; ocean literacy

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1. Introduction

The ocean profoundly impacts humanity, transcending geographic and cultural boundaries as the primary regulator of the global climate (Tanhua et al., 2024). At the midpoint of the UN Ocean Decade (2021–2030), ocean literacy emerges as a critical mechanism for empowering society to act towards ocean sustainability and health (Buchan et al., 2023). Recent developments in ocean literacy encompass awareness, activism, and adaptive capacity, fostering "meaningful public participation in ocean issues" (McKinley et al., 2023, p. 3).

1.1. The Human–Ocean System as a Complex System Beyond Anthropocentric Views

The Human–Ocean System (HOS) is a complex whole of interdependent components. Understanding it requires examining both the entire system and its parts, incorporating multiple perspectives, interrelationships, and dependencies. Effective human–ocean management demands the ability to address uncertainty and the complexity of system-wide impacts and dynamics (Arnold & Wade, 2015, as cited in Brennan et al., 2019). This contribution transcends traditional extractive and anthropocentric ocean views, embracing HOS as a complex system requiring a holistic understanding. Water is a dynamic, relational entity: central to ecological, cultural, and social narratives, demanding urgency in crafting methodologies and narratives that accelerate adaptation and mitigation in response to the intertwined climate and biodiversity crises. Water's intrinsic structure underscores its unifying role: as all life shares molecules and geographies shaped by water, we are inherently interconnected as citizens and beings within global water ecologies. The sustainability of humans relying on the ocean depends on the ability to understand this systemic approach. As a metaphor and material for the Hydrocene era (Bailey-Charteris, 2024), water reframes the human–water nexus, inspiring dimensions to move beyond the anthropocentric dynamic that is leading to SDGs (UN, 2015) moving and missing targets.

1.2. The Role of Ocean Literacy and Design in Addressing Complexity

Research indicates a limited public understanding of the ocean's importance and functioning (Fauville et al., 2018). The ocean is the matrix of our blue planet, playing a central role in regulating planetary systems and mitigating climate impacts (Intergovernmental Oceanographic Commission, 2020; Larkin et al., 2022), while it is simultaneously a focal point for addressing major challenges, including climate change, pollution, and biodiversity loss. However, ocean ecosystems face extensive pressure and exploitation from human activity (O'Hara et al., 2021). Ocean acidification, driven by human-induced carbon emissions, is poised to surpass another critical planetary boundary (Stockholm Resilience Centre, 2023, as cited in Richardson et al., 2023), underscoring the urgency for systemic change (see Figure 1, Supplementary File).

The complexity of the HOS extends to communication, cultural, social, and emotional dimensions—all areas of concern for design disciplines. These align with the capacity of design to address complexity in innovative and illuminating ways (Brown, 2009; Martin, 2009; Paton & Dorst, 2011; Verganti, 2009). To facilitate the required paradigm shift, it is essential to craft narratives that embed and embody societal knowledge, enabling informed decision-making across multiple levels—from policy development to broader considerations of water systems. This article argues for the integration of ocean literacy into ocean cycle-centric design (OCCD). OCCD, as a transdisciplinary and society-oriented framework, intertwines ocean literacy with design principles, expanding its boundaries and epistemologies.

The expansion of ocean literacy to address communication, cultural, and emotional dimensions (McKinley et al., 2023) intersects significantly with design disciplines. Design, inherently transdisciplinary, has long grappled with integrating diverse knowledge systems and societal impact. This shared ground offers opportunities to deepen the dialogue between ocean literacy and design, enhancing their combined ability to address urgent global challenges in complex times. In this article, "design," as a diverse discipline, is addressed for its role as the discipline that embraces and incorporates sustainability into its way of being, operating "for the real world" (Papanek, 1971). Design must adopt ocean-relevant cycles, as a connector guided by social, ethical, and ecological imperatives, where every action considers its broader impacts on society and the environment, resonating across multiple scales, and becoming ocean cycle-centric.

OCCD, informed by expanded ocean literacy, aims to embed a framework for navigating the interwoven challenges of the Anthropocene and Hydrocene eras.

The urgency to strengthen and restore the human–ocean climate nexus is increasingly evident. Accelerating efforts to overcome the barriers that prevent humanity from re-establishing a balanced relationship with the ocean and its interconnected bodies of water is essential. Design thinking tools and methodologies offer multiple opportunities and chances to deal with "unexpected dimensions in practice as well as understanding" (Buchanan, 1992, p. 5), engaging society and restoring this nexus at multiple levels. As further explored in this article, OCCD is guided by the vision of blue futures, aiming for a balanced, sustainable, and resilient human–ocean society nexus as an interconnected system.

Addressing societal behavioural change directly is crucial to ensuring the ocean health nexus: this imperative is reflected in the rewording of Challenge 10 of the UN Ocean Decade in 2024. As of May 2024, Challenge 10 (see Figure 2, Supplementary File) has been revised from "change humanity's relationship with the ocean" to "restore society's relationship with the ocean," with an updated goal to:

> Ensure that the multiple values and services of the ocean for human well-being, culture, and sustainable development are widely understood; that society-ocean connections are strengthened; and that there is increased motivation, capability, and opportunity for people across all sectors of society to make decisions and behave in ways that ensure a healthy ocean. (Glithero et al., 2024, p.18)

This reframing emphasises the critical need to foster understanding, motivation, and actionable engagement across society, aligning individual and collective behaviours with the goal of sustaining a healthy and resilient ocean ecosystem.

In the concept of Hydrocene (Bailey-Charteris, 2024), the water cycle highlights aspects deeply connected to design processes, particularly the life cycle of matter itself. Here, water is not merely "centric" but inherently "cyclic." Rather than being isolated or fixed, it is pervasive and dynamic. This paradigm shift is both multidimensional and transdisciplinary, functioning across diverse temporal and spatial scales while dissolving boundaries between disciplines and societal layers. As emphasised in the *Ocean Decade Vision 2030 White Papers*, societal engagement must go beyond the sustainable management of the ocean to encompass the management of human behaviour in ways that actively support ocean health. Ultimately, this focus underlines the critical need to reframe and nurture the human–water relationship as a cornerstone of global sustainability efforts. Design directly relates people to objects, systems, and environments through

porous projects, combining ways of knowing and acting from different traditions in design and social thought (DelSesto, 2022).

Drawing on the concept introduced in the June 2024 *Venice Declaration for Ocean Literacy in Action: How to Engage Society to Regenerate the Most Valuable Ecosystem on Our Planet*, this study seeks to establish a theoretical framework for understanding and defining this emerging idea. Specifically, it aims to address the following questions:

1. How can OCCD be defined?
2. How can we build a theoretical framework towards the applicability of OCCD?
3. What are the shared and overlapping dimensions between design thinking and ocean literacy?
4. Are there cases that align with the principles of OCCD when assessed using these indicators?

The framework proposed in this study aspires to clarify these questions and provide actionable insights, advancing the discourse on integrating design practices with the principles of ocean sustainability and regeneration.

2. Methods

The method outlined in this study (Figure 1) introduces OCCD, synthesising interdisciplinary frameworks from ocean literacy, design methodologies, and civic engagement. By combining models such as the double diamond and civic design method (Ross, 2022) with ocean literacy dimensions, the study creates a cohesive framework to bridge gaps in ocean-related design and human engagement. Central to this approach is the ocean cycle, which redefines human-environment interactions, integrating societal participation, ecological literacy, and innovative design. OCCD aims to be an enabler for emerging paradigms such as hydrofeminism, eco-aesthetics, and Hydrocene, weaving a blue thread across disciplines.

2.1. Conceptual Foundations and Definitions

The research begins by defining key concepts, such as the hydrological cycle, ocean citizenship, and Hydrocene, thereby establishing a theoretical foundation. The Hydrocene emphasises humanity's interdependence with aquatic environments (Bailey-Charteris, 2024), offering a lens for participatory governance and civic design. These concepts underpin the study's exploration of civic engagement and design innovation within the ocean society nexus.

2.2. Alignment Frameworks and Indicators

An alignment analysis of design methodologies—problem-solving, human-centred design, and OCCD—reveals their overlaps and differences in addressing societal and environmental challenges. The study proposes nine indicators for OCCD, tested through three case studies. These indicators are evaluated using the alignment table to demonstrate their practical application and alignment with ocean conservation goals.

2.3. Testing Indicators Through Case Studies

The case studies (As Close as We Get, the Whanganui River, and Explore the Ocean) validate the proposed indicators, bridging theory and practice to promote actionable outcomes. This approach demonstrates how OCCD can enhance societal understanding and responsibility toward ocean conservation. While challenges remain in balancing theoretical depth with practical impact, this framework offers a novel path for advancing resilient, ocean-centric design practices.

2.4. Strengths and Limitations of the Methodology

The interdisciplinary synthesis highlights the potential for integrating ecological and societal dimensions into design. However, relying on established frameworks may limit innovation, and S.M.A.R.T (specific, measurable, achievable, relevant, time-bound) criteria risk overlooking long-term, qualitative impacts. Despite these limitations, the study provides actionable insights, offering a unified framework that merges ocean literacy with design, advancing the goals of the *Ocean Decade Vision 2030 White Papers—Challenge 10*. The study's contributions lie in its creative integration of diverse frameworks and its emphasis on practical applications. The OCCD indicators aim to ensure a multi-perspective approach, addressing Challenge 10's objective of enabling existing knowledge to be used across society (Glithero et al., 2024).

By highlighting the synergies and overlapping points between existing ocean literacy frameworks (e.g., dimensions of ocean citizenship) and design methodologies (e.g., double diamond, civic design, and human-centred design), the study demonstrates how these can be combined to overcome disciplinary silos.

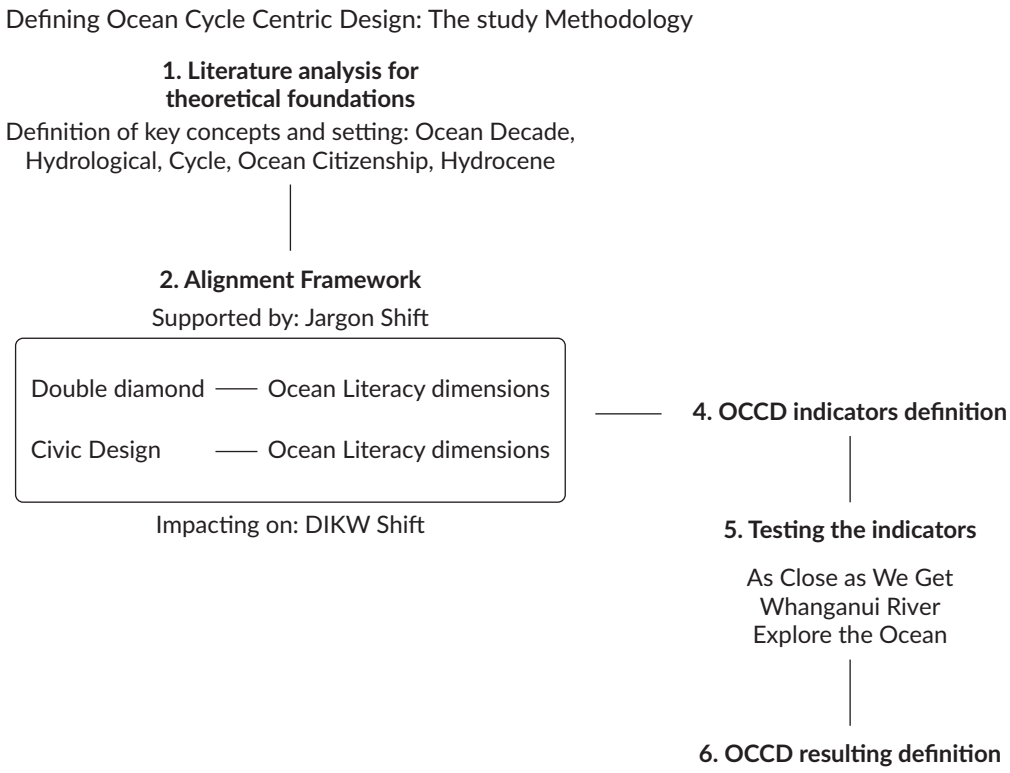

Figure 1. Study methodology Diagram. Note: DIKW stands for data-information-knowledge-wisdom.

3. Defining OCCD

3.1. Jargon Shift for Blue Humanities

The exercise proposed in this article establishes a foundation for defining a concept not yet present in the literature, identifying symmetries and connections between design dimensions and ocean literacy. It highlights the potential of navigating transdisciplinary correspondences between civic and ecosystemic design approaches and ocean literacy, moving beyond traditional disciplinary boundaries to embrace *ignotae aquae* (Latin for "unknown waters"). As illustrated by Annabelle Binnerts (Figure 2), this paradigm shift involves embracing uncertainty, "white space," and the boundaryless connector between entities—a porous, shared matrix traditionally represented in cartography through continents and countries.

The concept of OCCD is introduced by establishing essential terminology to characterise and frame this new idea. This framework addresses transformational challenges requiring a "fifth order of design," is the Planet, encompassing and expanding the four design orders: graphic, industrial, interaction, and system (Buchanan, 1992, as cited in Engholm, 2023). Addressing global challenges in this order involves integrating all artefacts and systems into strategic planning for a sustainable future, with heightened awareness of ecosystemic impacts (Engholm, 2023), and the complexity involved in the interconnectedness of the HOS.

McKinley et al. (2023) stress the need for new jargon and dimensions to expand ocean literacy across geographical and socio-cultural contexts. This article introduces a transdisciplinary vocabulary drawn from the blue humanities (Mentz, 2023b), emphasising word-building as a precursor to world-building. Extending

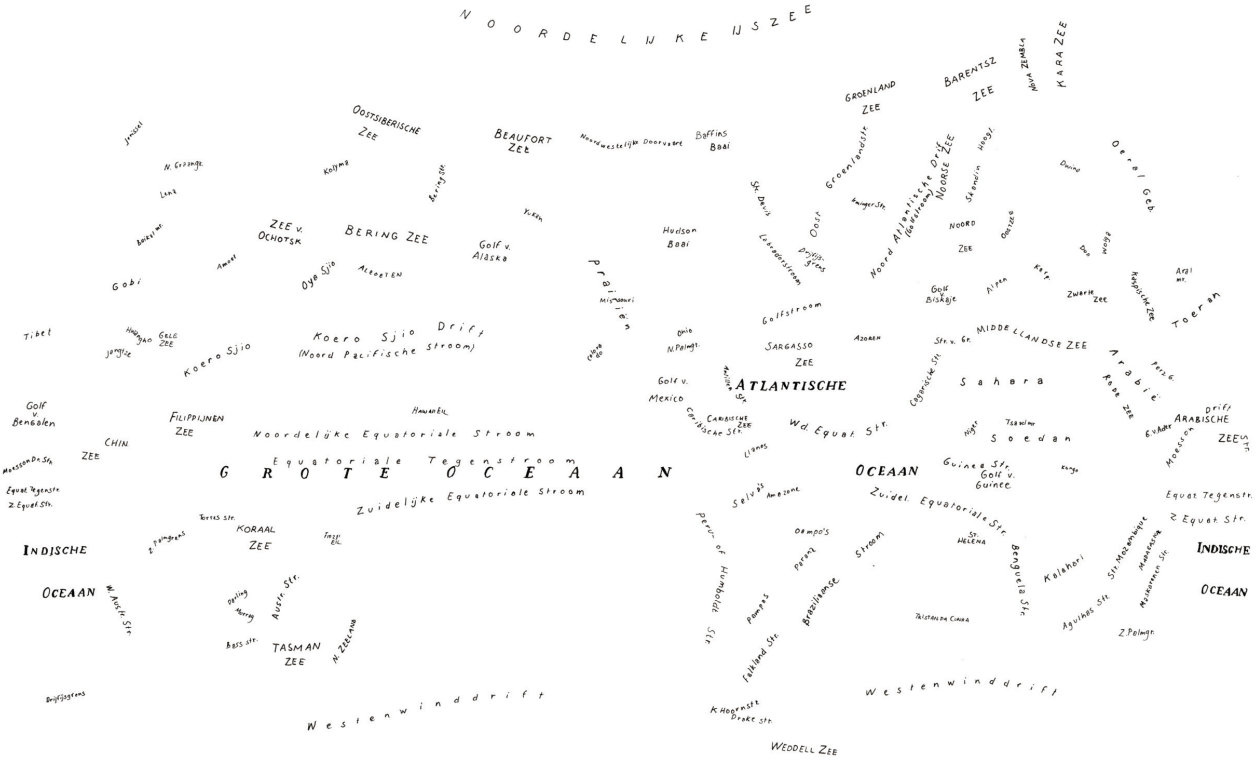

Figure 2. Wereldzeeën (in English, Seas of the World). Source: Binnerts (2017).

the hypothesis that "fluid-storied matter" can transform mindsets (Oppermann, 2023), towards a human-ocean-society nexus-balanced future.

Although the environment-centred design is well-established, the ocean-centric design lacks a defined epistemology. Mentioned in UNESCO's 2024 *Venice Declaration for Ocean Literacy in Action*, it catalyses a shift from humanity-centred design (Norman, 2023), broadening it to include species-wide relationships with ecosystems, and extending ocean literacy across education, science, policy, and culture. The Declaration asserts the need to:

> Launch transdisciplinary programs to better understand and inform our behaviour; merge natural, social, and behavioural sciences with humanities, spirituality and *ocean-centric design* in joint projects and studies. This approach values traditions but also evaluates them according to recent scientific findings. By fostering collaboration with non-academic stakeholders, Indigenous Peoples, coastal and local communities, we develop opportunities such as citizen science and nature-based solutions centred around knowledge, ethics, and experience. (IOC, 2024, p. 3)

Epistemologically, as emphasised by Mentz (2023a, 2023b) and McKinley et al. (2023), approaching new concepts requires the development of a new language. Bartlett et al. (2012) similarly challenge single-perspective frameworks, proposing a "two-eyed" approach integrating diverse knowledge systems. This article suggests shifting from "centric" semiotics to "cycle-centric" design. Commoner, in *The Closing Circle* (1972), considers how, in nature, all cycles are closed and balanced, forming a pillar of sustainability. Building on this, the ocean cycle is presented as a closed system, integral to and balancing planetary health. The term "cycle" refers to processes in the hydrological cycle, recycling water through evaporation, condensation, and precipitation across states and bodies of water—from droplets to rivers, oceans, and clouds (Inglezakis et al., 2016, pp. 137–212). This shift underlines how OCCD is confronted on a temporal and spatial scale (in terms of longevity and engagement) that transcends the sole human life and scale.

Embedding "cycle" into the design lexicon aligns with the continuous, interconnected nature of oceanic systems, encompassing temporal and spatial dimensions that are relevant on a planetary scale. As detailed in Part 4, the cyclical nature of oceans—evident in mechanisms like currents and water cycles—reflects processes with no definitive beginning or end. These cycles, extending from local to global scales, impact communities from coastal regions to urban areas. The cyclical process ensures that matter, whether autochthonous (originating within the system) or alien (introduced, like plastic pollution transforming into microplastics), persists within the system, undergoing constant transformation.

Operating within the ocean-cycle design implies that any introduced action, product, or process remains within the system, often for periods exceeding human lifespans. These actions cascade across geographic and ecological scales, amplifying the interconnectedness of all water bodies. Within cycles, exchanges between actors—human or natural—are inherently mutual, with varying but always-present porosity in human–ocean interactions.

As Mentz (2023b) suggests, adopting a "non-terrestrial" lexicon is necessary to immerse oneself in the blue humanities, smoothing the Human–Ocean Nexus starting with semantics. Moving from a centric to a cycle-based perspective represents a radical transformation in temporal, spatial, and material scales. These

dimensions, rooted in Mentz's (2023b) *New Dictionary of the Ocean*, demand rethinking design thinking, emphasising the interconnected and transformative nature of OCCD.

Table 1. Jargon shift for blue humanities (after Mentz, 2023b).

Dimension	Before	Now (Mentz, 2023b)	Extent/Scale
1. Space	Field	Current	Local to global scales
2. Time	Progress	Cycle and fluxus	Centuries, ages, and geological eras
3. Water	Soil	Water	Bodies of water (Ocean)
4. Humans	Individual (centric)	Community (interconnected)/ Society-Siphonophora	Society–humanity

The lexical shift towards currents, fluxes, and cycles is fundamental to addressing the needs of an ocean society, which is interconnected through the common matrix of water bodies and characterised by behavioural transformations that extend from individuals to entire societies.

3.2. Water Epistemology and Ocean Society

The HOS operates as a complex system of interdependent components. Understanding such a system requires examining its holistic structure and constituent parts. Humans' multifaceted engagement with the ocean necessitates an appreciation of multiple perspectives, interrelationships, and dependencies (Brennan et al., 2019). Within this framework, "cycle-centric design" is introduced to emphasise humanity's intrinsic connection to the ocean from multiple perspectives, highlighting the cyclic implications that extend from the scale of an individual human lifespan to that of future generations. It also acknowledges the broader, multi-scalar reality of belonging to a collective—society and humanity—that depends on the ocean for survival (ocean society).

Water, as the connective tissue of life, is foundational to this concept. The human body, composed of 60% water, parallels Earth's surface, which is 70% water. This symmetry underscores humanity's profound ties to the hydrological cycle. The continuous movement of water—through rivers, seas, clouds, and human bodies—creates a dynamic web of interactions, dismantling the notion of water as a static resource and reimagining it as a living system transcending boundaries. This perspective is visualized in Binnerts' (2017) conceptual "Wereldzeeën" (Figure 2), which maps water's interconnected flows and unseen connections.

Epistemologically, water's transparency, uncertainty, and fluidity support systemic thinking, while ontologically, these properties de-territorialize knowledge and practices (Mentz, 2023b). A single water sample—laden with chemical compounds, isotopes, and microplastics—encodes narratives that span local and planetary scales. This delayering transforms data into stories, dissolving traditional boundaries and fostering rethinking of spatial and cultural relationships.

Water functions as a living archive, reflecting the influence of human actions and cyclic natural processes. From ancient trade routes to acidified oceans, it bears witness to human and ecological narratives. These histories demand ethical care, accountability, and the construction of cartographies integrating ecological and cultural systems. The Hydrocene reframes water as both a participant in and witness to, the challenges of the Anthropocene (Bailey-Charteris,2024; Neimanis, 2012, 2017; Neimanis & Walker, 2014). This approach

aligns with marine citizenship, which extends Fletcher and Potts' (2007) concept to collective political actions. Knowledge, paired with rights, transforms ocean literacy into a tool for fostering sustainable practices and ethical human–ocean relationships (Buchan et al., 2023).

3.3. OCCD Dimensions

To explore intersections between ocean literacy and design, we used a visual overlap method (Figure 3) to support the integration of ocean literacy dimensions (McKinley et al., 2023) with the double diamond framework (Design Council, n.d.). This model includes four stages: discover, define, develop, and deliver, which emphasise deep engagement, collaborative idea generation, and iterative improvement. The double diamond has been utilised as an approach to integrate and trace a correspondence of ocean literacy dimension into process and design decision-making. The diamond, as with all design and strategic thinking, starts with a preliminary moment of "orientation and vision setting," which is a *sine qua non* of our envisioned action for the future we want. It prioritises people, inclusive communication, collaboration, and continuous iteration. The framework's success depends on strong leadership and stakeholder involvement, aligning with OCCD principles.

3.3.1. Knowledge, Access, and Experience: Explore

Figure 3 situates knowledge and access/experience within the "explore" phase, corresponding to the divergent opening of the double diamond. This phase broadens perspectives to gain insights into a given context, embracing a multi-perspective approach like "two-eyed seeing" (see Table 4). This implies a shift to a more active "explorer" role, which is characteristic of the "ocean citizen."

Exploration expands knowledge systems by incorporating diverse data, including Indigenous and overlooked knowledge, to develop a holistic understanding. Accessibility and experience should span disciplines and communities, enabling participants to interact with ocean knowledge via various media and platforms. Horizontal access to knowledge is critical, empowering non-specialist audiences to make informed decisions. Building trust across scales hinges on this access, linking knowledge, experience, and trust in meaningful ways. The process also acknowledges the unique languages and mediums of different knowledge systems, emphasising inclusive approaches to expand exploration and deepen understanding.

3.3.2. Awareness: Reframe

Awareness is positioned within the reframe phase, reflecting its dual role: awareness gain involves fostering societal recognition of humanity's interconnectedness with the ocean, from relying on it for oxygen and climate regulation to understanding it as part of a broader adaptive system. Achieving this awareness encourages a shift from an ego-centric to an eco-systemic worldview. Awareness in reframing uncovers the problem behind the problem (Paton & Dorst, 2011). Awareness gained through exploration aids in reframing challenges, fostering innovative solutions and actionable outcomes.

3.3.3. Attitudes and Emoceans: Connections and Relationships

Attitudes and emoceans (emotional connections to the ocean) align with the connections and relationships phase. This phase mediates between individual and collective scales, fostering societal understanding of how behaviours impact communities and the ocean.

Emotional connections to the ocean, referred to as "emoceans" (McKinley et al., 2023), are recognised as critical drivers of behavioural change (Jacobs et al., 2012). Research highlights how positive emotions enhance memory, learning, and engagement (Natalini, 2022; Pekrun, 2004; Pekrun et al., 2002), influencing attitudes and decision-making. Strengthening emotional ties to the ocean deepens individual and societal commitments to ocean health.

3.3.4. Trust and Transparency: Creation

Trust and transparency are integral to the creation phase, although they intersect with multiple dimensions of the double diamond. Their placement here is deliberate, building on connections and relationships to support processes that foster societal trust.

As Mentz (2023a) highlights, water's physicality is a metaphor for transparency in societal processes. Trust and transparency strengthen connections between scientific communities and non-specialist audiences. This is vital in the disinformation era—identified as a top risk in the *Global Risk Report 2024*. To counter this, fostering trust-building processes through transparency becomes a cornerstone of effective communication strategies.

3.3.5. Activism and Behaviour: Leadership and Storytelling

Activism and behaviour are situated within the leadership and storytelling dimension, recognising leadership as a means of transitioning from passive to active ocean citizenship. Activism is the degree of engagement in activities—such as campaigning for policy change (Brennan et al., 2019; McKinley et al., 2023). Leadership encourages collective action for societal transformation.

Storytelling plays a pivotal role in fostering engagement and connecting individuals with larger societal and ecological narratives. It bridges personal and collective scales, enhancing understanding and empathy (McDowell, 2021). As a tool for envisioning future scenarios, storytelling builds resilience and inspires behavioural change (Vervoort, 2014), making it central to cultivating a healthy society–ocean nexus.

3.3.6. Adaptive Capacity: Continuing the Journey

Adaptive capacity aligns with the continuing the journey phase, reflecting the need for societies to adapt to evolving challenges. Coastal communities depend on resilience and adaptive capacity to navigate the dynamic relationship between the ocean, climate, and coastline (McKinley et al., 2023).

This phase represents the culmination of the design process, encompassing acquired knowledge, emotional connections, and collaborative storytelling. Adaptive capacity emphasises the iterative, nonlinear nature of the journey, where feedback loops foster learning and continuous improvement. By weaving together diverse

knowledge systems and active participation, this phase operationalises a human–ocean nexus that is informed and responsive.

3.3.7. Communication: Core Dimension

Communication is positioned as a cross-cutting dimension, central to all phases of the double diamond. As an essential component of environmental and marine citizenship, communication connects communities, knowledge systems, and societal scales (McKinley et al., 2023).

Communication serves as the "delta," the liminal space where different knowledge systems converge and knowledge "catalyses." It encompasses both the content ("what") and the medium ("how") of knowledge transmission, employing traditional and innovative methods such as new media, technologies, and art-science. Effective communication fosters porosity between disciplines, enhancing information exchange and cultivating deeper connections between society and the ocean. It is integral to both the continuity and success of the journey.

Through these dimensions, OCCD reframes the human–ocean relationship, fostering ethical, ecological, and cultural sustainability.

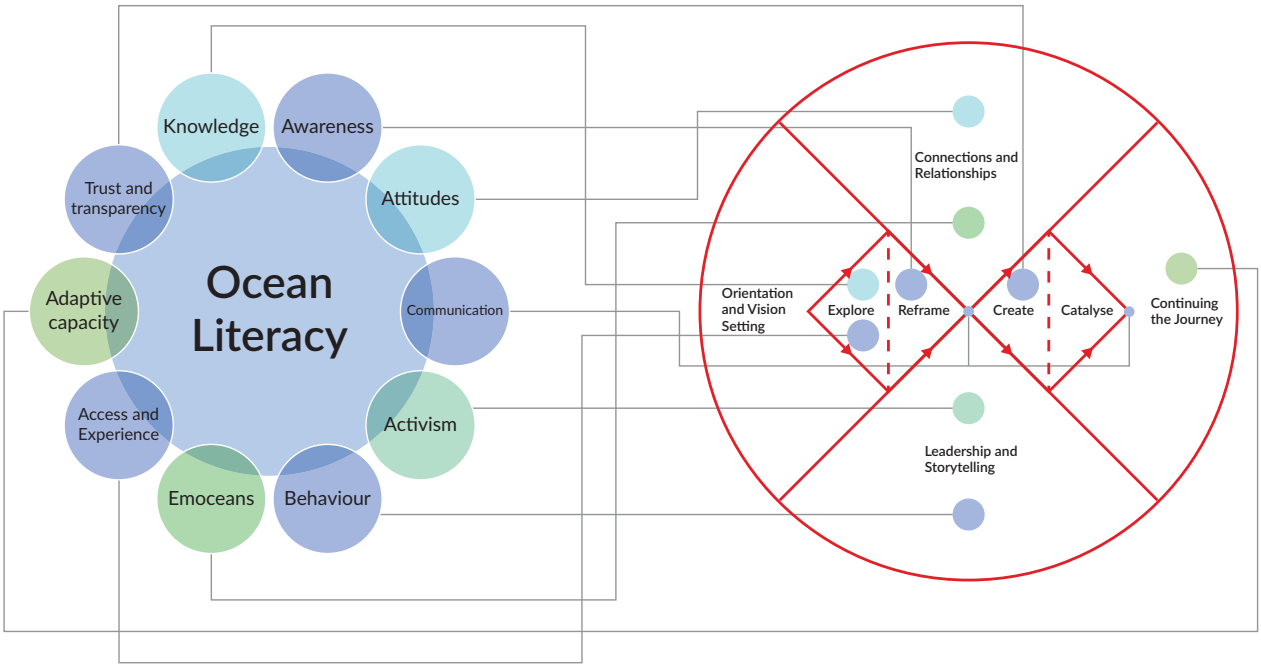

Figure 3. Ocean literacy dimensions and interaction within the systemic design framework. Based on McKinley et al. (2023) and Design Council (n.d.).

3.4. From Ocean Literacy and Civic Design towards OCCD Dimensions

In the following paragraphs, we present a set of tables (Tables 2 and 3) to facilitate the comparison of ocean literacy and design assets. Firstly, aligning ocean literacy with civic design extends its connection to the societal dimension. The comparison of design-based approaches, particularly problem-solving and

human-centred design, provides an opportunity to illustrate how OCCD contrasts with and expands upon these traditional frameworks.

Together with Table 1, these tables offer a structured overview of key elements and terminology encountered in OCCD. Table 1 aids in understanding the conceptual shift in terminology proposed by Mentz (2023b) and the scale of its impact. Table 2 enables a comparison of ocean literacy and civic design dimensions, derived from two key studies on societal engagement and impact, which, when integrated, contribute to the definition of OCCD. Finally, Table 3 refines OCCD indicators by evolving existing design approaches to better align with contemporary challenges.

The second part of the section is dedicated to the definition and representation of OCCD, embedding all the previous steps, to seek to foster societal behavioural shifts and overcome current limitations.

In Table 2, ocean literacy dimensions are compared to civic design dimensions (Fagnoni, 2022), considering civic participation fundamental to leverage existing knowledge to ensure a healthy ocean, supporting sustainable decision-making and the co-creation of actionable solutions.

Table 2. Comparison between ocean literacy dimensions (after McKinley et al., 2023) and civic design (after Fagnoni, 2022).

Ocean literacy dimensions (McKinley et al., 2023)	Civic design dimensions (Fagnoni, 2022)	Definition
Knowledge	Holistic approach	Practices/projects tend to consider systems and services as a whole, combining actions across multiple scales. No level of scale distinguishes these projects, nor a typology (span from product design, service design, communication design, and interior design)
Awareness	Civic engagement	Practices aiming to increase civic engagement and citizen involvement in decision-making. Participation is inherent in assumptions of what counts as civic (DiSalvo & Le Dantec, 2017)
Attitude	Interaction	Practices that maintain high interaction between people, between people and material or digital things; focusing on everyday interactions, whether between humans, with bureaucracies, or in groups
Behaviour	Ethic as material	Design as free from values and power, a form of innovation philosophy, and a set of heuristics for working with change in any context
Communication	Living futures	Exploration of alternative scenarios for design in 2050 revealed radically different possibilities for future societies. The role of designers varies depending on context, but ethics, as a system of guiding principles, is a common aspect (Bason, 2022)

Table 2. (Cont.) Comparison between ocean literacy dimensions (after McKinley et al., 2023) and civic design (after Fagnoni, 2022).

Ocean literacy dimensions (McKinley et al., 2023)	Civic design dimensions (Fagnoni, 2022)	Definition
Emotional connections	Design compelling communication and exchange	Design can inspire engagement and action around water bodies. Leveraging emotional responses by creating inclusive spaces, storytelling platforms, and participatory experiences that encourage empathy, collective responsibility, and co-creation, promoting behaviour change for marine preservation
Access and experience	Inclusive ocean experiences	Creating opportunities for people to engage with the ocean, physically or virtually, ensuring access regardless of location, gender, physical limitations, or cultural background. Design removes barriers such as cost and social factors while enhancing emotional connections to the ocean.

The co-creation of actionable solutions, embedded within all civic design dimensions, necessitates the positioning and sustaining of co-design processes in which citizens play a crucial role (Dal Buono et al., 2020). Citizens have the potential to contribute local knowledge and perspectives on civic issues, synthesise data, and innovate new solutions (Reynante et al., 2021). Co-design involves integrating local knowledge as a fundamental component of design actions for the "real world" (Papanek, 1971) while also reframing civic participation as the primary challenge in driving behavioural shifts across society.

The comparison of design-based approaches (Table 3), particularly problem-solving and human-centred design, provides an opportunity to illustrate how OCCD contrasts with and expands upon these traditional frameworks. This highlights the distinct characteristics of OCCD, emphasising its ecological interconnectedness, systemic thinking, and emphasis on sustainability—elements that extend beyond the traditional scope of problem-solving and human-centred approaches. From this alignment, the identified indicators in Table 3 are then integrated and expanded into the eight dimensions of OCCD (Sections 3.4.1–3.4.9).

Table 3. Comparison of design-based approaches' indicators, after Junginger (2014) and identified indicators of OCCD.

Problem-solving approach	Human-centred design approach	OCCD
Concerned with isolated problems	Concerned with indeterminate situations	Concerned with interconnected issues that threaten the marine environment and humans. It considers humans as part of the marine biome. It involves porosity between disciplines as a complex system Identified indicators: Embracing uncertainty and interconnectedness

Table 3. (Cont.) Comparison of design-based approaches' indicators, after Junginger (2014) and identified indicators of OCCD.

Problem-solving approach	Human-centred design approach	OCCD
One-directional, linear, top-down, though with feedback loops	Works simultaneously in several directions, neither top-down nor bottom-up but rather crisscrossing through an organizational system (Junginger, 2009), thereby mixing its elements	Transdisciplinary, crisscrossing, and circular Identified indicators: Transdisciplinarity and porosity
Frames policymaking as a response mechanism; policymakers passively wait for a problem to appear and then respond, promoting reactive rather than proactive policy design	Envisions futures and develops scenarios to bring them to life	Is able to embrace radical paradigm shifts and scenarios. It works on anticipative futures Identified indicators: Blue futures and radical scenarios
Predominantly a discovery and selection of already existing alternatives	Begins with inquiry, includes discovery and selection, but also promotes invention	It is based on research and feeds new inquiries, but invention and innovation are a needed asset in its inception phases. It encompasses uncertainty and the unknown Identified indicators: Circular innovation and multi-perspective
Fragments the design process Treats policymaking as one design activity: the policy is the primary designed product, while policy implementation is the secondary	Integrates the different design efforts through participatory, collaborative, and co-designing methods that inquire into all elements of a system (cf. Sanders & Stappers, 2008; Bason, 2010)	A holistic approach that takes into consideration the complexity of the process in a system. The system is intended as more than the sum of the parts, bringing added value and mechanisms (Brennan et al., 2019; Meadows, 2009) Identified indicators: Holistic and systemic
Presents policymaking as an abstract exercise centred on decision-making, without considering the experiences and realities of the people affected by the policy—citizens, external stakeholders, and public employees	Includes and involves people to learn about issues and opportunities for improvement in particular situations. Civil servants, ordinary citizens, external stakeholders, public managers, and others relevant to a situation, product, or service often participate, collaborate, and co-create toward a solution	Citizens and communities are actively involved in decision-making, policymaking, and scenario ideation. Solutions, services, projects, and processes are based on the involvement of multi-stakeholders. This involves non-humans as a community that holds rights and needs at the consultation tables Identified indicators: Connecting communities and ocean citizenship
Values design solely for its problem-solving ability, using it only as an instrument for policy implementation	Covers the whole range of designing, including inquiry, discovery, and invention	Embraces the multiple perspectives crossing scales and dimensions (two-eyed seeing method; Glithero et al., 2024) Identified indicators: Multi-perspective

Table 3. (Cont.) Comparison of design-based approaches' indicators, after Junginger (2014) and identified indicators of OCCD.

Problem-solving approach	Human-centred design approach	OCCD
Takes policy design out of its context, suggesting that a policy problem can be treated in isolation	Situates and integrates the design of policies and policymaking in organizational life, but also within the human experience of everyday people	Policymaking aligns and is designed through civic active participation, local communities' needs, and is based on ecological impact and scenarios Takes into consideration how local and global issues are deeply interconnected. Every solution needs to be context-specific but must benefit its next scale (e.g., river to the sea and sea to the ocean) Identified indicators: Multi-scalar and local to global
Relies on abstract data drawn from the past	Relies on actual and present human experiences	Relies on practical data, human experiences, values, and behaviours. Citizen science is integrated into local cartography. Local and indigenous knowledge is embedded to expand it. Mapped perceptions and emotions are taken into consideration. Data is harmonised and open access Identified indicators: Harmonised DIKW-A (data, information, knowledge, wisdom, and action)
—	—	The use of resources takes into account the cyclicity of the water cycle, its temporality, and its extent Identified indicators: Matter-cyclic and multi-species

3.4.1. Multiscalar

The term multiscalar refers to the various governance levels that influence and shape actions centred on the ocean cycle. A multiscalar approach to policy and governance is increasingly recognised as essential in strategic planning (Sorensen, 2018). Ensuring harmony and compliance across governance scales—from global to local—can enhance the likelihood of success. This alignment not only supports the implementation of ocean-related initiatives but also improves access to financial resources, fostering more effective and integrated outcomes.

In OCCD, policymaking is shaped by and aligned with civic participation, responding to the needs of local communities while being grounded in ecological impact assessments and scenario planning. This process recognises the profound interconnection between local and global challenges, acknowledging that environmental and societal issues do not exist in isolation but rather form part of a larger, interdependent system. The overarching aim is to foster alignment with the principles of an ocean society, where human activities are harmonised with ocean health and sustainability. Achieving this vision requires co-design as a

fundamental approach, enabling collaboration across different sectors of society and ensuring that diverse voices and knowledge systems contribute to decision-making. Effective policymaking must, therefore, be both context-specific and scalable, addressing immediate local concerns while also fostering solutions that benefit interconnected systems. For instance, interventions at the river level should not only resolve localised issues but also support the health of downstream ecosystems, from the sea to the ocean, reinforcing a holistic and integrated approach to sustainable governance.

3.4.2. DIKW-A

Building on the imperative of fostering an ocean-informed society, it is crucial to examine how knowledge and information shape decision-making (Sinni, 2023). The DIKW chain (Figure 4) structures our understanding of the ocean, yet knowledge alone is insufficient for meaningful action. Blue epistemology highlights the gaps in defining data and wisdom while underscoring the challenge of fostering engagement towards blue citizenship. Knowledge enables process understanding, informing individual and collective actions. Through synthesis, reflection, and the application of lessons learned, wisdom emerges, integrating ethical and aesthetic values into decision-making (Ackoff, 1989). Expanding the DIKW model to include action (DIKW-A) reinforces the link between wisdom and purposeful action, creating a dynamic, circular system aligned with long-term goals (Ackoff, 1989; Rowley, 2007). However, this progression is complex, as data collection can reflect biases (D'Ignazio & Klein, 2020), and excessive information may lead to polarization rather than clarity (Cairo, 2016). To address these challenges, DIKW-A integrates inclusivity, infrastructure, and storytelling to present knowledge effectively and stimulate behavioural change (Mitra & Sameer, 2022).

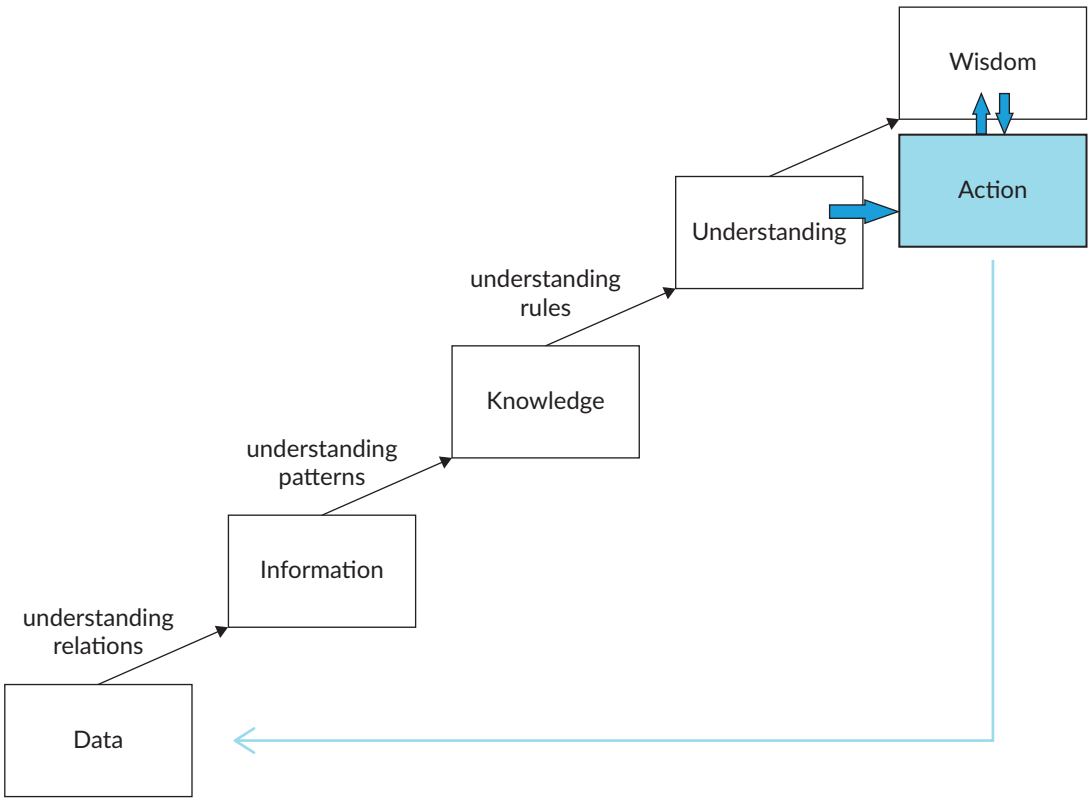

Figure 4. DIKW-A chain. Note: Adapted from Bellinger et al. (2004).

The knowledge pyramid in OCCD is expanded to emphasise the flow between wisdom and action (DIKW-A), with particular attention to fostering behavioural change (see Section 4). OCCD incorporates a broader spectrum of data and knowledge, harmonising diverse knowledge systems to create actionable insights. This aligns with the Challenge 10 white paper, which stresses the necessity of integrating varied knowledge types for broader societal application. The DIKW-A chain is a transformative process that accelerates transitions to informed decision-making, innovative solutions, and increased awareness and attitudes towards the ocean and water systems. The shift from data to wisdom and action is enabled through tools such as the European Digital Twin of the Ocean and the Atlas of the Seas. These tools facilitate transdisciplinary collaboration (Glithero et al., 2024) and connect diverse scientific datasets through harmonised infrastructures. Importantly, these tools must also remain accessible to non-specialists and other stakeholders, fostering widespread engagement. Citizen science data, for example, offers additional layers of understanding, enriching cartographic efforts while promoting civic participation. Similarly, emerging narratives and new media formats (e.g., AR, VR, XR, data physicalization, and sonification) make information and knowledge more engaging and experiential, enhancing accessibility for non-specialist audiences (McKinley et al., 2022). These methodologies aim to accelerate adaptation and mitigation efforts in response to the climate and biodiversity crises, highlighting the interconnected nature of ecological challenges and emphasising shared responsibilities across society.

3.4.3. Blue Futures

OCCD's time horizon must extend beyond immediate human lifespans to account for future generations. This approach aligns with the concept of "continuing the journey" from systemic thinking, emphasising the development of anticipatory futures and forward-looking scenarios. Creative and radical paradigm shifts are central to this methodology, offering scientifically grounded narratives of potential future oceans. A pertinent example is the Radical Ocean Futures (n.d.) project, which uses these narratives to focus attention and drive behavioural change by illustrating the long-term implications of today's actions. Specifically, blue futures could be assimilated and aligned to the "preferred future" axis as depicted in the cone of possible futures by Voros (2003, 2020).

3.4.4. Holistic and Interconnected

OCCD broadens the design scope from local to global scales, reflecting the interconnected nature of water systems. This holistic approach recognises the inextricable linkages between different bodies of water—including rivers, lakes, seas, and ice formations—through the global water cycle. These entities are ecologically interconnected, either directly or indirectly, through processes such as evaporation and condensation. Additionally, a holistic approach challenges traditional geopolitical boundaries. Water bodies, and their associated environmental challenges, often extend beyond political borders. For instance, rivers serve as major conduits of ocean plastic pollution (The Ocean Cleanup, 2024). Inland waterways transport pollutants from urban areas to oceans, exemplifying the interconnectedness of terrestrial and marine systems and underscoring the need for comprehensive, boundary-crossing solutions.

3.4.5. Embracing Uncertainty and Multiperspective

The society-ocean nexus is a highly interconnected and complex system, linking human life, marine health, and environmental processes through the hydrological cycle. Addressing these interconnections requires

OCCD to engage with the inherent uncertainty of this multidimensional system. An approach rooted in embracing, rather than limiting, uncertainty expands the capacity to navigate "uncharted waters," epistemologically and practically speaking. Designing for uncertainty fosters interdisciplinary collaboration and facilitates the integration of diverse perspectives (Overbeek & Bessembinder, 2013). OCCD calls for a multiperspective framework, such as the "two-eyed seeing" approach (Glithero et al., 2024), which combines Indigenous and Western knowledge systems. Extending this concept, OCCD proposes a "hundreds-eye seeing" perspective, inspired by multi-species collectives like Siphonophorae. This approach leverages insights from diverse human and non-human viewpoints, emphasising collective and systemic interdependence.

3.4.6. Matter-Cyclic

In cyclic systems, interactions between actors are reciprocal. Actions—whether human or natural—create impacts that ripple across assets and processes. The concept of cyclic matter in OCCD centres on water, the primary material of the hydrological cycle. As an "infinite-cycle" resource, water continuously flows and transforms within natural cycles. However, human activities introduce non-cyclic materials, such as pollutants and microplastics, which persist in these systems long after their initial introduction. These long-term consequences necessitate careful consideration of spatial, temporal, and material flows that transcend the human scale, impacting deeply marine ecosystems and non-human life.

3.4.7. Ocean Citizenship: Community Engagement

Ocean citizenship emphasises active participation in informed decision-making and behavioural change. Being a citizen of the ocean entails adopting a "blue-informed" societal mindset, which fosters actions that contribute to ocean health from individual to collective action. This concept underscores the collaboration between diverse communities to build relationships across societal layers, strengthening OCCD processes. A metaphor for this concept is the Siphonophorae, a marine collective organism (a zooid colony) composed of interconnected individuals and communities. Harmonising individual, community, and societal actions fosters resilience and sustains the entire system's health.

3.4.8. Multi-Species

OCCD acknowledges that human societies coexist with an array of non-human actors, including animals, ecosystems, and technologies (Giaccardi et al., 2024). This perspective is particularly critical for marine ecosystems, which face overexploitation and endangerment due to human activities. The multi-species approach broadens the traditional human-centred perspective to include non-human viewpoints, fostering a deeper understanding of marine biodiversity and its interconnectedness. Notably, despite the ocean being Earth's largest ecosystem, only 5% of it has been explored (National Oceanic and Atmospheric Administration, n.d.). This vast unknown underscores the need to respect, discover, and integrate knowledge of yet-unexplored species and ecosystems into OCCD "hundreds eye-seeing" knowledge systems.

3.4.9. Porosity Index

Drawing from Mentz's (2023a, 2023b) dictionary for blue humanities, OCCD incorporates fluxes, currents, and cycles as defining dimensions. Porosity serves as both a physical and metaphorical concept, reflecting the

fluid exchange of ideas, disciplines, and interactions between humans and ecosystems, in a transdisciplinary way. This concept aligns with Barad's (2007) use of physical phenomena as knowledge metaphors. In nature, water permeates and mixes across surfaces, creating liminal spaces and porous boundaries between entities such as river deltas where fresh and saltwater meet. At the micro-scale within a porous medium, water functions as a connector, forming a dynamic liquid mesh that links different spheres. Similarly, if we try to visualise the dimensions of OCCD as distinct spheres in a four-dimensional space (Figure 5a), OCCD dimensions are included in a cone of possible futures (Voros, 2003, 2020) extending to a blue future where

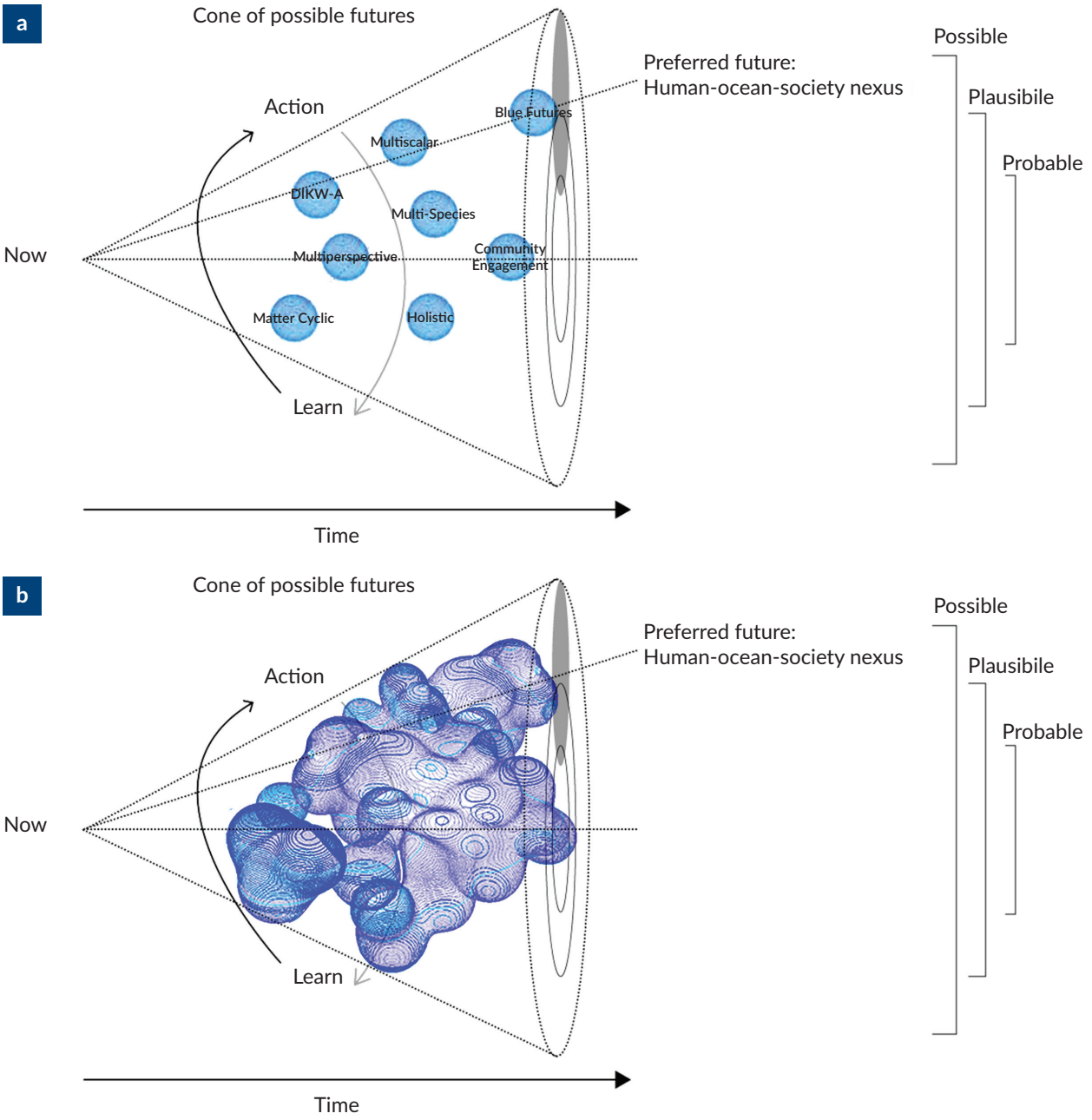

Figure 5. (a) Diagram of OCCD dimensions in a four-dimensional context of cones of possible futures; (b) representation of OCCD, as a four-dimensional connector of the different dimensions aiming to a preferred future where the human-ocean-society nexus is fully accomplished. Note: Figure 5a was adapted from Voros (2003, 2020).

the human-ocean-society nexus is balanced. Through cyclic processes of learn and action iterations, running between the different dimensions—ranging from individual to systemic scale—OCCD can be visualised as an evolving, amorphous mesh (Figure 5b). This fluid structure continuously adapts, integrating and interconnecting different OCCD dimensions, reinforcing its role as a unifying and dynamic framework.

OCCD fosters high porosity between disciplines, entities, and systems, allowing knowledge and processes to flow freely and enrich one another (Figure 5). In the chosen case studies, different degrees of exchange persist, emphasising the interconnected nature of all systems. The porosity index is evaluated, in this study, according to three levels of intensity: high, medium, and low.

4. OCCD: Case Studies

This section presents three case studies selected for their alignment with the dimensional assets of OCCD as defined by indicators in Section 3. These examples, drawn from the past decade, are intentionally diverse, representing various facets of OCCD. Each case study highlights the presence of certain dimensions and the absence of others within the OCCD framework, offering an opportunity to use these gaps as starting points for discussion, illustrating how integrating the absent dimensions could strengthen and enhance future OCCD approaches. The selected cases are examined through a critical yet forward-looking blue future perspective, viewing them not as finalised projects but as evolving, cyclic examples with significant potential for further development and deeper integration of OCCD principles.

They emphasise community engagement at multiple levels—from policymakers to local communities—and contribute to achieving Challenge 10's goal of restoring society's relationship with the ocean. The guiding principles for selection included:

1. Addressing transdisciplinary aspects (time, space, and matter) in an ocean cycle-centric approach.
2. Involvement of local communities in the decision-making process.
3. Consideration of the project's ecological and biome impacts using a multi-perspective and multi-species lens.
4. The introduction of DIKW-A society, leading to increased awareness to lead tangible behavioural changes.

4.1. SUPERFLEX: As Close as We Get

4.1.1. OCCD Indicators: Multispecies, DIKW-A, Multi-Scalar, Blue Futures, and Matter-Cyclic

The art-science installation As Close as We Get exemplifies the intersection of marine spatial planning, ecology, art-science, and material research. Created by SUPERFLEX with DTU Sustain and By & Havn, it features three "monoliths" in the Copenhagen Harbour. The project, part of the Super Rev programme, aims to restore reefs and promote marine biodiversity using sustainable, biocompatible materials.

The installation uses CO_2-absorbing concrete with a "sponge-effect," developed by DTU Sustain, to capture carbon and create marine habitats, aligning with the matter-cyclic ocean cycle centric indicator. This regenerative approach builds on projects like Vigo Port and ECOncrete technology.

The installation prioritises marine biodiversity, viewing harbours as spaces where human and non-human life interact. Materials, from ancient stone to modern fish-friendly bricks, embody a temporal continuum, reflecting the project's vision for a blue future. Underwater, the sculpture serves as a habitat, while above water, it engages the public, blending ecological function with artistic expression.

As Close as We Get demonstrates the DIKW-A chain by turning material research into an actionable prototype, raising awareness and enhancing public understanding of marine ecosystems. The project also reimagines urbanism within the Hydrocene, where water dominates global ecosystems and coastlines are a shifting and changeling boundary, offering a model for future harbour policies and multi-species urban design. This pioneering project merges ecological regeneration, material science, and public engagement, serving as a blueprint for sustainable urban–marine symbiosis.

4.2. Whanganui River

4.2.1. OCCD Indicators: Holistic and Systemic, Community Engagement, Multiperspective, DIKW-A, Blue Futures, and Multi-Species

In March 2017, the Whanganui River in Aotearoa, New Zealand, became the first river globally to be granted legal personhood. This recognition stems from viewing the river as a living entity and spiritual ancestor of the Whanganui Iwi, a Māori tribe (Kramm, 2020). The case is a significant advancement in legal pluralism, redefining humanity's relationship with non-human entities like water bodies (Charpleix, 2017).

The Whanganui River case is inherently holistic, considering the river's vast geographical extent of 290 km across Aotearoa New Zealand. This spatial reach has played a crucial role in uniting the riverine communities that have inhabited its waterways for centuries. The Whanganui Iwi ontologically conceive and understand the river as an indivisible, living entity, and as the spiritual ancestor of the Māori people residing along its shores. For generations, Māori settlements have been established along the river's course, with Whanganui—meaning "big harbour" in Māori—regarded not only as a vital source of food and healing but, more significantly, as the embodiment of the Iwi's ancestors (Kramm, 2020).

In this context, the river as a spiritual and living entity serves as a tangible example of a multi-perspective and multi-species approach, aligning with Giaccardi's conceptualisation of an extended network of non-human actors. Beyond its fundamental role in human survival—as a food source, a waterway for transport, and an essential ecological system—the river is deeply embedded in the Iwi's language, beliefs, and social structures, acting as a source of food, single highway and spiritual mentor (Charpleix, 2017). Recognised as a less anthropocentric approach, the Whanganui River case is particularly significant in the discourse of environmental management, especially in relation to water governance (Charpleix, 2017).

The Whanganui River represents a co-design experience (as co-design is intended in Zhang et al., 2024), understood as a system of collaborative processes that engage diverse communities and contribute to the advancement of water body policies on a global scale. The relationship between the Whanganui River and its community illustrates how Indigenous knowledge, cultivated through centuries of symbiotic coexistence and aligning with the DIKW framework at the wisdom level, ultimately leads to action in policymaking and large-scale community engagement.

The legal personhood of the river, established through the Te Awa Tupua Act, was achieved following a century-long struggle between the Whanganui Iwi (a Māori tribe) and the New Zealand Government. The Whanganui Māori have been advocating for their rights over the river since the colonisation of the 1840s (Charpleix, 2017). Kramm (2020) provides a detailed examination of the bureaucratic structures and processes—comprising guardians, a strategy group, and an advisory group—that facilitated the recognition of the river's legal personhood and its practical implementation. This legal status enables the river to be represented in court, with two appointed guardians acting on its behalf.

4.3. Explore the Ocean

4.3.1. OCCD Indicators: Community Engagement, Multiperspective, DIKW-A, and Blue Futures

The design process employed by the Science Communication Lab, as outlined by Landis and Duscher (2022), is notable for its interdisciplinary approach. Scientists and designers collaborated iteratively to transform research into a visually cohesive language tailored for specific audiences. This process involved testing and revisions with the target audience to refine the product (Landis & Duscher, 2022).

Explore the Ocean's process is innovative compared to other spatial representations, even official ones. For instance, national geoportals for maritime spatial planning often lack participatory features, restricting co-design opportunities (Davret et al., 2023) in spite of official requirements for engagement (Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning, 2014). To foster inclusivity, testing user-friendly interfaces and incorporating public engagement during planning stages are essential (Barbanti et al., 2023).

This approach effectively communicates complex scientific concepts by connecting with audiences on visual and emotional levels. The interactive poster introduces scientific topics engagingly, demonstrating design-driven science communication through interactive storytelling. It covers aspects of the ocean system, including geodynamics, the biosphere, climate, and observing systems, and addresses challenges like plastic pollution and overfishing. This mirrors the DIKW-A chain (data to action), a key framework in this study.

Explore the Ocean is an example of the DIKW-A framework, by bridging the DIKW-A at various levels. On one hand, it underlines the importance of knowledge sharing and raising awareness through storytelling methods (double diamond processes) in supporting the behavioural shifts that are essential for sustainable ocean management.

The concept of "revision loops" aligns with circular design principles, such as the double diamond framework, reinforcing co-constructed knowledge with society. Audience feedback was crucial in refining the product, creating a dynamic loop between science and the public. The focus on emotional resonance supports ocean literacy goals, enhancing engagement with marine systems.

The Explore the Ocean poster is an effective tool for public interaction with marine science, ensuring transparency and credibility (Duscher et al., 2017). The use of innovative 3D visualisation creates an immersive experience, demonstrating how design, communication, and scientific research converge to make marine science more accessible and relevant, advancing OCCD principles.

5. Results: Comparison of Case Studies on Ocean Cycle-Centric Indicators

Table 4. Comparison of OCCD indicators in case studies, porosity ranking level (low-medium-high).

	3.5.1. Multi-scalar	3.5.2. Dikw-A	3.5.3. Blue futures	3.5.4. Holistic and inter-connected	3.5.5. Uncertainty and multi-perspective	3.5.6. Matter-cyclic	3.5.7. Community engagement	3.5.8. Multi-species	Porosity index
(a) As Close as We Get	X	X	X	–	–	X	–	X	Medium
(b) Whanganui River	–	X	X	X	X	–	X	X	High
(c) Explore the Ocean	–	X	X	–	X	–	X	–	Low

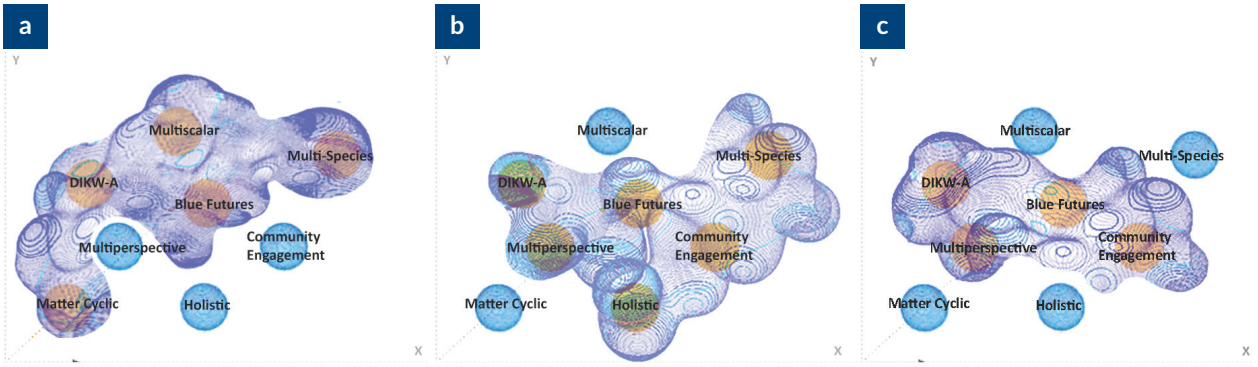

Figure 6. Diagram representing the OCCD approach, in a four-dimensional, fluid form. Note: The variations depend on the active OCCD dimensions and their interconnectedness for the selected case studies (a, b, and c) as named in Table 4.

In Figure 6, we present the active indicators within each case study (a, b, and c), illustrating how OCCD, depicted as a four-dimensional mesh, shifts in shape and density around the different indicators (1, 2, and 3). This visualisation aims to emphasise the fluid and evolving nature of OCCD, highlighting its capacity to adapt over time. Additionally, it underscores how the missing indicators in each case study can be integrated through future developments and iterations, allowing for continuous evolution and refinement of the OCCD framework.

The results are organised in Table 4. As it shows, each case study can be related to numerous indicators. As Close as We Get exemplifies a matter-cyclic approach, emphasising how human structures within harbours can prioritise biodiversity and the marine biome. Through its design, the project seeks to transcend anthropocentric life cycles by incorporating the hydrological cycle and the complexity of ecosystems in a more-than-human approach. It offers a vision of a blue future, addressing the preservation and regeneration of harbours and endangered coastal ecosystems and habitats.

Rooted in transdisciplinarity, the project bridges art-science, research, engineering, and ecosystem-based management. It reflects a collaborative process between disciplines that includes innovations in material science and public art to reimagine human interactions with marine environments. Community engagement in this initiative has been a bottom-up process, driven by Copenhagen's municipal strategies and projects

such as Living Ports. However, the project's primary objective is fostering citizen's curiosity and awareness through its sculptural and ecological design, focused on increasing a multi-species perspective and interaction of harbour's ecosystem health.

This study acknowledges the absence of a co-design approach in this case, a highly relevant aspect of the Ocean Decade's success, as indicated by Zhang et al. (2024). However, it must be said that it is a contemporary challenge to shift from a "design for" to a "design with" methodology, as well as to involve all relevant stakeholders (Zhang et al., 2024). This transition reflects the complexity of integrating participatory design practices and active civic engagement, which require significant changes in both mindset and process. That is why the Whanganui River case study is particularly meaningful, as it demonstrates a multi-scalar community engagement in the co-design of the river's legal personhood, highlighting how collective action can shape and redefine governance models.

The Whanganui River exemplifies a holistic perspective, spanning its geographical extent and integrating scales from local communities to national recognition in Aotearoa, New Zealand. Historically, the river has been a vital connector, facilitating Indigenous knowledge transfer and providing a foundation for DIKW-A processes. This was realised through community-led advocacy, culminating in legislative change via the Te Awa Tupua Act, which granted the river legal personhood.

The interconnectedness of the human–ocean nexus is deeply embedded in this example, with the porosity between the river's life and the communities living alongside it extending to a multi-species perspective. This perspective was instrumental in achieving the river's legal personhood, demonstrating how cultural and ecological Indigenous wisdom can influence and design contemporary policymaking.

A critical factor in this case is the duration of the Iwi community's efforts—over 60 years of sustained advocacy to recognise the Whanganui River as a legal entity. This long-term commitment reflects a blue futures perspective, wherein the interplay of intergenerational wisdom and persistence offers a model for other ecosystems seeking similar legal recognition. However, it also highlights the challenges such processes entail, requiring considerable time, resilience, and community solidarity.

The Explore the Ocean initiative engages fewer OCCD indicators compared to the previous examples but holds value as a dissemination-focused project. Its integration of DIKW-A is evident in how raw marine data is transformed into information, knowledge, and narratives. While it did not directly contribute to policymaking or tangible actions, its approach offers inspiration for potential future initiatives that might connect awareness-building efforts with actionable change.

The project's strength lies in its transdisciplinary and porous methodology, uniting marine science, graphic design, and interactive technology to create a compelling ocean literacy output. By providing an immersive, data-rich exploration of ocean systems, it demonstrates the potential of storytelling to expand public understanding. The initiative emphasises porosity across disciplines, encouraging a blend of scientific rigour with creative communication to engage diverse audiences.

Moreover, Explore the Ocean supports a blue futures outlook by fostering public engagement and imagination through its interactive storytelling. While the initiative primarily enhances the visitor experience on cruises,

its accessible and visually captivating design promotes an understanding of ocean dynamics and potential human impacts. Such projects can inspire innovative educational tools to bridge the gap between scientific knowledge and public awareness, offering new avenues to envision sustainable marine futures.

These three cases collectively underscore the importance of integrating OCCD principles into diverse domains. As Close as We Get highlights how harbour infrastructure can embody biodiversity and regenerative practices using innovative materials and art-science integration. The Whanganui River demonstrates how community engagement and Indigenous wisdom can lead to transformative legal and policy changes over time, advocating for a holistic and multi-species approach. Explore the Ocean offers a model for connecting scientific knowledge with public engagement, emphasising immersive and interdisciplinary storytelling as a pathway to inspire action.

Together, these examples reflect a spectrum of approaches to fostering interconnectedness between human and non-human marine systems, offering a blueprint for future strategies rooted in sustainability, collaboration, and long-term impact. The exercise shows that it is possible to evaluate actions and their design processes according to the indicators and the proposed framework.

6. Conclusions

Inspired by the *Venice Declaration for Ocean Literacy in Action* (IOC, 2024), we sought to analyse the concept of "ocean-centric design" and explore its application in real-world scenarios. Through examining established sources on ocean literacy and design, we developed a framework called "OCCD," aiming to support innovative solutions that strengthen the human-ocean nexus. This framework builds on systemic thinking, civic design, and hydrocenic epistemologies, addressing the multifaceted relationships between individuals, societies, and the ocean.

Drawing from Brennan et al. (2019), ocean literacy involves understanding the ocean's influence on individuals and humanity, as well as their influence on the ocean. An ocean-literate person not only grasps the importance of the ocean but also communicates its significance effectively and makes informed, responsible decisions about its resources. However, translating these decisions into actions requires design approaches that integrate perspectives, scales, disciplines, and communities, fostering sustainable relationships with the aquatic environment. In terms of research questions, we can now define OCCD as a transdisciplinary, systems-based approach that integrates human and non-human perspectives to address interconnected marine and environmental challenges. It emphasizes holistic, multi-scalar, and anticipatory thinking, considering humans as part of the marine biome while fostering circular innovation, radical scenario planning, and ocean citizenship. OCCD promotes civic engagement, inclusive policymaking, and participatory design, leveraging local, Indigenous, and scientific knowledge to create sustainable, context-specific solutions that benefit both local ecosystems and the global ocean cycle. It aligns design with ecological impact, embraces uncertainty, and operates across disciplines to generate adaptive, future-oriented strategies for marine preservation and human-ocean interactions.

Thanks to the indicators we identified, we have shown that there are already examples that align, at least partially, with the principles of OCCD because they explored the interconnection of humans and the marine environment while being concerned for the future and having a holistic approach. However, the limits in terms

of community engagement, multilevel governance, and porosity, prove that there is still room for improvement to achieve a full OCCD.

Our study demonstrates the feasibility of bridging ocean literacy dimensions (McKinley et al., 2023) with design frameworks, highlighting overlaps between civic design and ocean literacy. Notably, a shift in jargon and language is critical to influencing behaviours and maritime oceanic mindsets. The overlaps showed that ocean literacy and design thinking share a systems-oriented, participatory, and experiential approach to fostering engagement, knowledge, and action. The assessed dimensions highlight transdisciplinary, action-driven, and inclusive methodologies that connect the two disciplines for a more systemic impact.

By exploring society's various relationships with the ocean, we devised a conceptual framework merging ocean literacy and design, identifying and testing a set of indicators through three significant case studies. This analysis revealed that designers and citizens can foster a more holistic interaction with the ocean by embracing multiperspective approaches and embedding socio-environmental considerations.

The envisioned success for Challenge 10 includes cultural and behavioural shifts towards a healthier ocean and more effective communication of ocean science across societal layers. Building on this, we propose evolving the definition of an "ocean-literate" individual into an active "ocean cycle-centric designer and citizen."

An "ocean cycle-centric designer and citizen" recognises the interconnectedness between their life and the ocean's health, acting as a Hydrocene epoch citizen who creates, acts, and improves systems while considering their socio-environmental impacts in a multiperspective and multiscalar manner. This approach accounts for the hydrological cycle's temporal dimensions, extending beyond human lifetimes to include multispecies and transgenerational impacts. It also expands the physical scale of actions from local to global, reflecting water's role as the unifying element of the Hydrocene epoch, connecting aquatic ecosystems and human communities on a planetary scale.

In addition to fostering informed decision-making, this perspective emphasises exploring potential, data-supported futures beyond traditional political agendas. Such exploration is essential for evaluating solutions to extreme situations and advancing sustainability, ensuring that both ocean literacy and design contribute meaningfully to societal and environmental resilience to navigate the future's *ignotae aquae*.

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Conflict of Interests

The authors declare no conflict of interests.

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Setting Sail for Resilience and Ocean Sustainability

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Abstract

This article makes a valuable contribution to the emerging field of marine social sciences by focusing on the potential contribution of learning theory and praxes in promoting ocean literacy, marine identity, and marine citizenship. These are advocated as important social dimensions of the changes and outcomes required to promote sustainability and resilience of marine environments and, by extension, terrestrial environments, across a range of scales from local to planetary. This is because the factors that compromise marine resilience are largely anthropogenic, and a consequence of the negative outcomes of human disassociation from the ocean. From another perspective, the article is equally concerned with how to promote personal resilience and ocean stewardship as positive personal and social outcomes exhibited by people, especially young people. A synergy is noted between outdoor adventurous education and inquiry-based science learning in marine contexts, with sail training being identified as particularly effective as a marine-oriented experiential learning approach and context. These insights are exemplified through a case study of sail training programmes developed and operated in the UK. Preliminary findings from trainee questionnaires support the contention that sail training is a powerful vehicle for personal growth across the range of learning dimensions (upward, outward, inward, and downward personal growth). Feedback also indicates the development of ocean literacy, marine identity, and marine citizenship amongst some participating trainees which, together, promote personal resilience and a commitment to marine stewardship (advocates of and active agents for promoting ocean sustainability).

Keywords

environmental and sustainability education; marine citizenship; ocean literacy; outdoor education; sail training

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1. Introduction

This work is motivated by the insight that a healthy and sustainable planet, and ultimately human well-being, is dependent on the marine environment and that the actions of humanity are compromising the health and resilience of this life support system, which must change (Intergovernmental Oceanographic Commission, 2021). However, this perspective remains largely restricted to a relatively small sector of society, including academics, practitioners, and policymakers working and researching at the forefront of human-(marine)environment relations. In order to change the attitudes and behaviours of the wider public, a sea-change in the relations between the greater part of humanity and the environment—the marine environment specifically—is required.

The designation of 2021–2030 as the United Nations Decade of Ocean Science for Sustainable Development represents a welcome moment in this urgent and necessary process. The associated seven visions for a future resilient and healthy ocean represent a framework for such a renewed human-marine relationship (Intergovernmental Oceanographic Commission, 2021). In particular, Outcome 7 expresses the need for "an inspiring and engaging ocean where society understands and values the ocean in relation to human well-being and sustainable development" (Intergovernmental Oceanographic Commission, 2021, p. 19) and promoting ocean literacy is seen as an important social outcome of the UN Decade. This is, however, predicated on the need to address the UN Decade's Foundational Challenge 10:

> Ensure that the multiple values and services of the ocean for human well-being, culture and sustainable development are widely understood and identify and overcome barriers to behaviour change required for a step change in humanity's relationship with the ocean. (Intergovernmental Oceanographic Commission, 2021, p. 23)

This demands suitable exploratory and explanatory frameworks in order to identify appropriate interventions, which might facilitate the transition of people from a situation of non-engagement to one of awareness and engagement with human-marine relations (Glithero et al., 2024). Initially, such growing awareness was largely driven by natural scientists, who identified the knowledge required to make people ocean-literate from a scientific perspective (National Marine Educators Association, 2013). More recently, there has been an accompanying "blue turn" in the sociological, arts, and humanities disciplines (McKinley et al., 2020; Popova et al., 2023), this journal itself being an important marker in this respect. This has given rise to a range of marine environmental communication strategies aimed at bridging the gap in awareness (Lindland & Volmert, 2017), and to new and emerging humanistic and sociological concepts such as ocean citizenship (S. Fletcher & Potts, 2007), marine citizenship (Buchan et al., 2023), and marine identity (Buchan et al., 2024). There has also been a similar turn in the realms of human health and development, with physical and mental health benefits of being near, on, or in the water being increasingly recognised (Britton & Foley, 2021; MacIntyre et al., 2019; Nichols, 2015) alongside the possibility for deeper, more existential, and spiritual dimensions of human-aquatic relations (e.g., Shaw & Francis, 2014).

Crucially, what remains acknowledged yet relatively under-theorised is a focus on the *learning* dimension—at the individual and collective/social levels. This article contends that deeper learning is required, driven by direct experiential and inquiry-driven learning engagements, and aims to contribute to these efforts by building on learning theory and praxis already apparent within the field.

2. The Contribution of Significant Learning and Development Praxes

2.1. Dimensions of Learning and/or Personal Growth

In this section, we broadly map out human dimensions across which learning might occur, by drawing on emerging work at the intersection between psychology (environmental, developmental, and evolutionary), psychotherapy (including ecotherapy), sports and leisure studies, and education (outdoor, experiential, adventurous, environmental, etc.; Fink, 2013, p. 7). Whilst making general observations, we focus specifically on how these insights might be related to the affordances of human-marine relations.

2.1.1. Experiential Learning

Experiential learning represents a broad and complex field, comprising many currents (Roberts, 2012). Arguably, learning, or experience of any kind, can only take place as an emergent property of three inextricable dimensions of experience (Falk & Dierking, 2013): the physical setting (indoors or outdoors), social context, and intrapersonal or mindset. The transaction between the outer setting (interpersonal/social and/or physiographic contexts) and the inner context is achieved through the experiencing (and by extension learning) individual.

The notion of the "experiencescape" (O'Dell & Billing, 2005) represents an emergent property of these three contexts. From this perspective, "the particular attributes and affordances of the place are crucial; but so, too, are the subjectivities (motivations, perceptions, responses, etc.) of the 'experiencing subjects' " (Morgan & Freeman, 2022, p. 86). One can distinguish between experiencescapes that are everyday and those that are strange or unfamiliar, typically distant "awayscapes" (Morgan & Freeman, 2022). The latter are often seen as potentially effective for transformative learning precisely because of their unfamiliarity. Residential experiences and expeditions present a range of "challenges of being 'away' from: home, supportive friends and familiar territory; and being 'relocated' into a (potentially) challenging: physical environment; social environment (including living communally and completing tasks in groups); and travelling long distances" (Morgan & Freeman, 2022, p. 86). It is precisely because these challenges require effort to overcome and afford the opportunities for encountering the unknown that they present such a powerful learning context (Bell et al., 2010). This article is concerned with a specific experiencescape (seascape) and awayscape (a sail training vessel; Brown, 2016; Roe & Stead, 2022, p. 350).

Beatley (2017, p. 126) presents the range of opportunities for seascape encounters as a "blue pyramid." The base represents local, short-term, and accessible opportunities to engage with the blue environment, such as taking a walk along the coast, going for a swim, or fishing from the shore. Ascending the pyramid involves increasingly lengthy and immersive, but less frequent, experiences likely to involve increasing travel to faraway seascapes, including potentially offshore and out of sight of land. This model is particularly relevant in this article since sail training represents an activity towards the apex of the pyramid. This makes it arguably more costly (in time, finances, and resources), raising important challenges in terms of scaling up and exclusivity. However, we argue that it is particularly effective for promoting deep, meaningful, and transformative learning engagements with the marine environment, providing suitable efforts are made to make it accessible and inclusive.

2.1.2. Directions of Personal Growth and Development

The simple framework utilised by Stott et al. (2015, p. 224) derived from their work on youth expeditions indicates that positive growth or learning outcomes can occur in four dimensions:

1. Upward personal growth (realising potential): increased confidence, physical and social resilience, self-reliance, and ability to overcome challenges.
2. Outward personal growth (learning about others): improved social skills.
3. Inward personal growth (learning about self): improved emotional stability and better able to reflect on events.
4. Downward personal growth (learning about the environment): increased environmental appreciation and awareness.

The first and third dimensions relate to personal development (emotional intelligence, self-esteem, and self-efficacy; Peterson & Seligman, 2004; Schiro, 2008). It also implies pursuing *eudaimonia*—achieving the highest level of personal development or flourishing, such as the upper levels of Maslow's (2013) hierarchy of need: self actualisation and self-transcendence (these contribute to personal resilience). The second dimension concerns learning to relate to other people, i.e., developing interpersonal, intercultural, or social understanding. These represent complementary and synergistic orientations of growth—learning about and with others drives personal growth or maturation, and vice versa. It is usual to combine or conflate them as personal and social development or spiritual, moral, social, and cultural development. Claims as to the positive learning potential concerning these three dimensions represent key justifications for sail training as a vehicle for youth development (E. Fletcher & Prince, 2017; McCulloch et al., 2010; Prince & Fletcher, 2020).

The fourth growth orientation relates to the environment, which can include seascapes. This can be experienced at the local scale of the "nearby" or "place-based," but can also involve abstractly learning about scales beyond the local, extending to the global. Environmental and sustainability education (ESE) and inquiry-based approaches to environmental learning are likely to emphasise this downward/external dimension. Scientific inquiry (e.g., learning about natural processes and systems), particularly if undertaken experientially through fieldwork, is a key orientation in ESE, which can help to identify characteristics leading to optimal ecosystemic health and/or issues that threaten the resilience of the environment. Alternatively, more affectively oriented and expressive approaches to ESE drawing on the arts and humanities have been developed. Ultimately, intellectual and affective engagement is seen as the necessary precursor to agency and environmental citizenship.

2.1.3. Domains and Dimensions of Learning and Growth

Educational psychology typically distinguishes between three main domains, each of which can be a focus for learning: the cognitive (intellectual), affective (emotional), and psychomotor (embodied/sensorial experience), through which behaviour is expressed. Such distinctions hide the interrelatedness of these three domains (Beard & Wilson, 2006). Nevertheless, the distinctions can be helpful analytically. For example, Rieckmann (2017) used a similar formulation in considering the range of learning opportunities related to the Sustainable Development Goals (SDGs; United Nations Development Programme, n.d.):

> The cognitive domain comprises knowledge and thinking skills necessary to better understand the SDG and the challenges in achieving it. The socio-emotional domain includes social skills that enable learners to collaborate, negotiate and communicate to promote the SDGs as well as self-reflection skills, values, attitudes and motivations that enable learners to develop themselves. The behavioural domain describes action competencies. (Rieckmann, 2017, p. 11)

Various models have been proposed to account for the processes that lead to environmental behaviour change (Akintunde, 2017). Furnishing people with the requisite information is insufficient to engender behaviour change. Nor is it sufficient merely to locate oneself in nature. Lumber et al. (2017) suggest that additional pathways for deeper engagement are required. This relates to recent work in positive psychology and nature connection, which identifies the salutogenic benefits of physical access to, and engagement with, green and blue spaces (e.g., Donnelly & MacIntyre, 2019; Newton, 2007). The concept of the blue mind (Nichols, 2015) supports the particular benefits of engagement with aquatic environments, and there are many autoethnographic accounts of the deep and meaningful engagements people have next to, on, in, and underwater, including marine environments (e.g., Brown & Humberstone, 2016; Morgan, 2019). Many of these accounts relate to *hedonic* pleasures of embodied engagement with the natural, and specifically aquatic, environment; others relate to more *eudaimonic* growth.

2.1.4. Knowledge, Skills, Attitudes, and Values

Another analytic approach much utilised in educational theory identifies knowledge, skills, attitudes, and values (KSAV) as different targets or outcomes of learning. Formal schooling often emphasises transmitting content and/or procedural knowledge in designated *indoor* spaces (classrooms) that can be replicated in assessment situations. This relies on extrinsic instrumentalist motivations to compel such learning and does not always promote engagement and attitudinal or behavioural change. Informal learning, by contrast, can take place in any context and is:

> Not just for advancing academic study but also for personal and social development. It…seeks to promote human flourishing by acknowledging and extending the lived experience of learners, establishing and pursuing *their* wants and needs as the basis for developing their agency. (Morgan & Freeman, 2022, p. 84, emphasis added)

Informal learning allows learners to freely choose the content and approach of the learning undertaken for intrinsic reasons, which is particularly relevant in relation to this article in terms of "environmental free-choice learning" (Falk et al., 2009).

The values dimension can form a specific focus. Two broad approaches are discernible (Halstead, 1996). Values clarification seeks to allow people to develop a personal understanding of, and response to, particular issues such as are encountered through inquiry and debate. This approach is pertinent to complex socio-scientific issues (Levinson, 2006; Ratcliffe & Grace, 2003), such as ESE and coastal and marine citizenship. Character development, in contrast, relates to the idea of pursuing *eudaimonia*, achieving one's full authentic potential and promoting particular character traits or virtues (Peterson & Seligman, 2004). Claims to support character development and resilience represent a major justification for sail training.

2.2. Educational Approaches That Intersect

2.2.1. Outdoor Adventure Education

Some argue that interaction with the natural environment, particularly in the context of adventurous activities, can facilitate the development of character and virtues, such as courage, endurance, resilience, persistence, self-control, and self-mastery. Typically, outdoor adventure education (OAE) activities "include a small-group atmosphere, interaction with an outdoor or natural setting, a purpose-driven dynamic for achieving specific goals, an uncertainty of outcome, and a sense of achievement on completion of the experience" (Ewert & Sibthorp, 2014, p. 3). Context and setting are important, typically involving:

> [A] juxtaposition of beautiful and aesthetically pleasing scenery combined with a challenging and demanding physical environment combined with a critical and novel social environment…[which] can provide not only challenge and excitement but also connection to nature, places for reflection and quiet solitude. (Ewert & Sibthorp, 2014, p. 34)

Of particular importance in many models of OAE is the inclusion of real or perceived risk and/or challenge, which is deemed crucial in the promotion of personal growth. Thus, participants are required to move beyond their comfort zone to discover hidden dimensions of themselves, whilst simultaneously increasing their physical fitness and well-being. Such a perspective lies at the heart of many formulations of OAE and expeditionary learning (Stonehouse, 2010), of which sail training is a special instance (Marshall et al., 2020). Indeed, the particular logistics of life aboard, a necessarily cramped and self-sufficient vessel at sea in a dynamic, challenging, and unfamiliar environment, are likely to promote insights into the need for collaboration, prudent use of resources, resilience, and problem-solving—a microcosm of the virtues required for a more sustainable world. Other dimensions of character and virtue promoted by intimate engagements with the natural world may include: ecological sensitivity attunement and attentiveness; temperance, frugality, and far-sightedness; and wonder, reverence, benevolence, and compassion (Sandler, 2006, 2007). Opportunities to engage with the marine environment afford particularly edifying experiences not possible otherwise, such as engaging with marine wildlife in their natural habitat, spectacular seascapes, sunrises, and bioluminescence.

A purely risk-driven OAE approach has come under criticism as being overtly masculinist and elitist, prioritising exceptional achievements, leading to often negative environmental or cultural impacts. More recent formulations are more conscious of issues of equality, diversity, inclusion, and community, to pay due attention to the local ecosystems through place-responsive practices and engagements, and the need to reduce carbon footprints (Brown & Beames, 2017).

Much OAE practice is limited to short activities within a day-long or perhaps longer residential program. However, a particularly powerful OAE strategy is to undertake an extended expedition into relatively wild environments, especially if undertaken using traditional, non-motorised modes of transport (Henderson, 2010), including sail, which affords being closer to, and beholden to, the natural, elemental forces (wind, tides, currents, etc.).

2.2.2. Socio-Scientific Inquiry-Based Learning

There is a long-standing tradition of undertaking scientific expeditions, notably since the Age of Enlightenment, which developed into their use as an educational vehicle for promoting scientific literacy in the 20th century (Stott, 2010). More recently, greater emphasis has been placed on education for environmental citizenship (Hadjichambis & Paraskeva-Hadjichambi, 2020) through socio-scientific inquiry-based learning, community service learning, civic ecology education, and place-based and problem-based learning. Such approaches have the potential for a range of positive outcomes, namely: enhanced knowledge and skills concerning scientific topics and scientific inquiry; interest in science, nature, and the environment; an associated motivation to, and sense of self-efficacy in participating in scientific activities and debates; and behaviour change and stewardship—local through to global (Bonney et al., 2016; Phillips et al., 2018).

Such approaches have increasingly been used in relation to the marine environment, and in order to promote ocean literacy, marine identity, and marine citizenship, through "coastal and marine citizen science" (Cigliano & Ballard, 2017; Fauville et al., 2019). Many such initiatives are understandably oriented towards the base of the blue pyramid, i.e., typically shore-based activities in coastal localities. Some might involve near-shore and underwater activities, such as snorkelling and scuba diving (Cigliano & Ridlon, 2017). There is, however, an emerging recognition of the particular value of using vessels as a learning platform capable of going further, and for longer, offshore and accessing seascapes/awayscapes higher up the blue pyramid. The use of sailing vessels for this work lessens environmental impacts.

This article advances the contention that sail training presents a suitable context and strategy for combining in a synergistic manner the benefits of adventurous outdoor education and inquiry-based scientific learning in a maritime context to promote ocean literacy and marine citizenship. The following section seeks to support this contention through the presentation of a case study.

3. Case Study: Ocean-Focused STEAMS Education Aboard Tall Ship Pelican of London

3.1. Background

The tall ship Pelican of London is a UK-based sail training vessel operated by a not-for-profit youth development organisation. The impact evaluation data obtained from the Pelican of London trainees is used here with the express agreement of the organisation, which meets three core objectives (personal growth, career development, and ocean literacy) through residential sail training programmes that engage young people in the age range of 14 to 25.

Voyages aboard Pelican are typically six to ten days in duration and have a complement of seven professional crew, six to nine volunteer crew, and up to 30 trainees. The latter come from a broad range of backgrounds and include many young people who experience challenges in daily life, may it be socio-economically, neurodiversity, or societal marginalisation.

3.2. Programme Development

The integration of ocean-focused STEAMS (science, technology, engineering, arts, maths, and sustainability) education and sail training aboard Pelican is an innovative attempt to utilise the synergies between residential OAE, ESE, and socio-scientific inquiry-based learning in supporting youth development, ocean literacy, citizenship, and identity. The concepts and factors underpinning this educational approach are summarised in Figure 1.

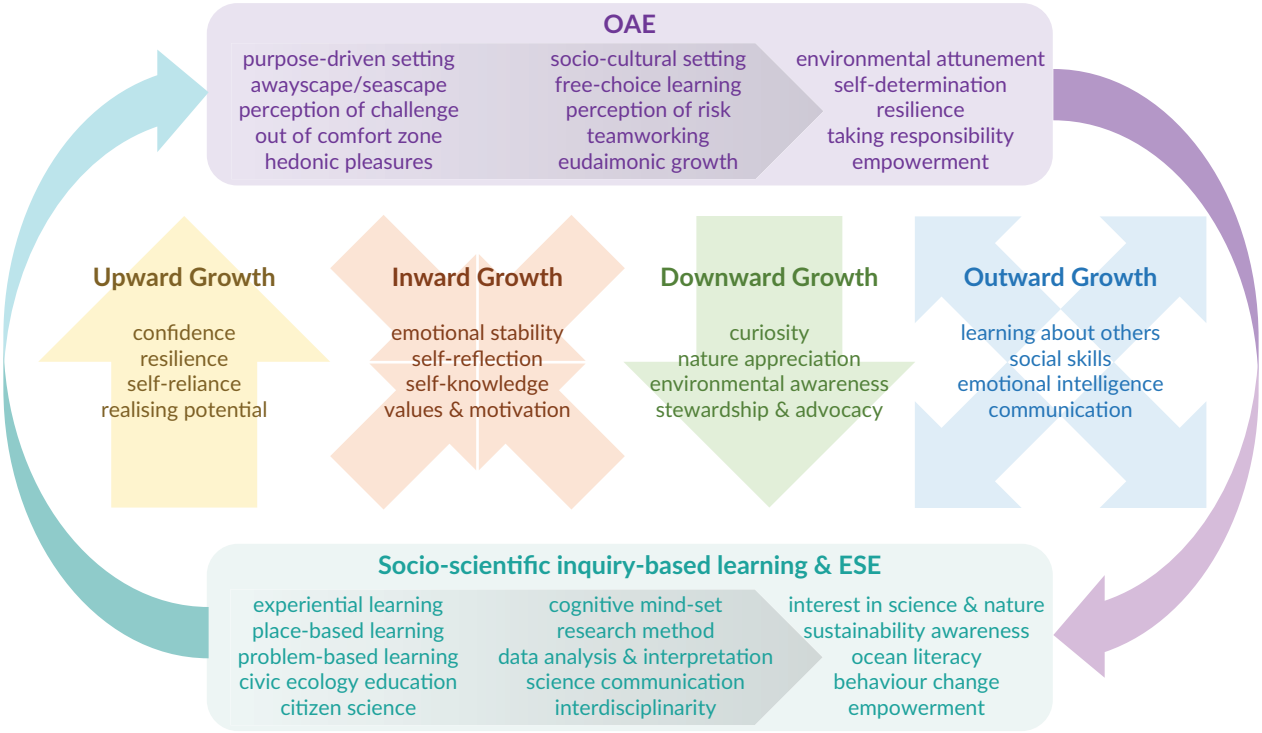

Figure 1. Synergies between OAE, socio-scientific inquiry-based learning, and ESE promote upward, inward, downward, and outward personal growth, with desirable outcomes in the context of this case study. Note: Based on Bonney et al. (2016); Marshall et al. (2020); Phillips et al. (2014); Sandler (2007); Stott et al. (2015).

At first glance, tensions between the hierarchical structure on a sail training vessel and developing self-reliance and empowerment may be detected, which also extend to the discipline required in scientific enquiry. Within the case discussed here, these tensions are envisioned to be resolved by the upward personal growth effected by the training programme, lasting beyond the time on board.

The integration of STEAMS education into sail training on Pelican originated with the ambition to better utilise the potential of being at sea by enhancing the ocean literacy and marine identity of trainees, with the aim to promote marine citizenship. An experienced marine scientist and expeditionary educator (co-author), developed and delivered a series of ocean science pilot voyages between 2019 and 2021. Based on these experiences and with the typical length of the summer voyages (7–10 days) and different audiences in mind, the projects Ocean Awareness, STEAMS at SEA, and Ocean Science were established in 2022.

Our approach utilises the potential for transformative experiential learning in the seascape of a residential voyage on a sail training vessel. The synergies of youth expeditions that promote upward, outward, inward,

and downward personal growth (Stott et al., 2015) with learning opportunities through STEAMS education was seen as a potentially powerful pathway towards behavioural change and marine citizenship (Figure 1). In this context, the principles of ESE and inquiry-based learning were combined with the UN SDGs (United Nations Development Programme, n.d.) to guide the development of workshops, experiments and citizen science activities that also encourage creative expression and complement the sail training objectives:

- The ship's crew encourage trainees to look after their own and each other's health and well-being (SDG 3 "good health and well-being"), embrace diversity and gender equality (SDG 5 "gender equality" and SDG 10 "reduced inequalities"), and showcase a wide range of professional pathways (SDG 8 "decent work and economic growth").
- The education programme introduces atmospheric processes and impacts of anthropogenic climate change (SDG 13 "climate action") and explores the ocean (eco)system (SDG 14 "life below water"). It includes human impact studies and encourages reflection on personal choices and behaviours (SDG 12 "responsible consumption and production"). Learning to generate quality data for citizen science projects empowers ocean advocacy and stewardship beyond the voyage.
- Training and education goals are achieved through hands-on experience with a range of sailing and STEAMS challenges, experiments, design competitions, and observations that support knowledge and skills acquisition for people with different learning styles (SDG 4 "quality education").

The extent and depth to which this is achievable depends on the voyage model, age, and educational interests of the trainees:

- Ocean Awareness voyages add value to young people's sail training experience through having a scientist in residence on board, who offers voluntary participation in science outreach activities. Scientists in residence may pursue their own interests and engage trainees by leading discussions and introducing data collection for citizen science projects.
- STEAMS at SEA voyages incorporate a programme of activities into the daily sail training routine. Led by an experienced STEAMS educator, all trainees take part in workshops involving scientific observations, experiments, and calculations in subject areas that are relevant to their experience at sea.
- Ocean Science voyages are a more research-oriented variant of STEAMS at SEA. Trainees are introduced to the scientific research process and design and execute research projects in small groups, from asking a questions to disseminating the outcomes of their investigation.

Since 2022, three Ocean Science, 10 STEAMS at SEA, and 24 Ocean Awareness voyages have taken place, involving approximately 70, 250, and 600 trainees, respectively. The voyage models differ in resource requirements in terms of the pedagogic experience of the science lead, equipment, and time set aside for STEAMS within the training programme.

Citizen science activities are a valuable part of all voyages, as they engender discussions of ocean conservation, introduce concepts of quality control, provide valuable data, and empower individuals to take citizen science into their daily lives and communities. Little equipment and training are needed and their potential for developing ocean literacy, marine identity, and marine citizenship is high. The STEAMS and Ocean Science voyages extend the personal development facilitated by sail training and citizen science by enhancing key employability skills and boosting confidence in academic subjects through immersive

experiential learning. In this, cognitive, socio-emotional, and behavioural learning objectives (LOs) related to the UN SDGs are realised, with the focus on the former while on board and longer-term aims for the latter two. To illustrate this within UN SDG 14 (after Rieckmann, 2017, p. 38):

- Cognitive LO: development of understanding of basic marine ecology, food web relationships, and the role of the ocean in climate regulation through learning while on board.
- Social-emotional LO: maturing of the learning that took place on board through further engagement post-voyage, resulting in the ability to show others the impact of human activity on oceans and reflect on their own consumption and waste management choices.
- Behavioural LO: post-voyage, feeling empowered, and motivated to take informed action (e.g., debate and campaign for conservation; identify and source sustainable products).

Achieving such LOs requires a more experienced expeditionary educator, who is comfortable with the flexibility and adaptability necessary when working with diverse groups, and challenging and changing conditions at sea. In addition, equipment that enables the study of ecosystems (e.g., plankton net, microscopes, hydrophone, and underwater camera), oceanography (e.g., current meter, sonar, and sediment grab), chemistry (e.g., laboratory and analytical instrumentation), meteorology (e.g., weather station), and more, is necessary for facilitating experiments and observations that support this deeper learning.

3.3. STEAMS Practice Onboard

The provision of a flexible, engaging, and hands-on learning environment that is distinct from the classroom is particularly important for young people with negative experiences in formal learning environments. The informal educational setting on Pelican affords the application of free choice learning principles. For example, for a session of around 45 minutes, a small group of trainees could be given the choice between undertaking meteorological observations and learning how to read the sky or to experimentally explore the impact of rising atmospheric CO_2 levels on ocean chemistry and ecosystems. The former is relevant as weather directly shapes our experience on board, while the latter brings together several strands of knowledge related to examining phytoplankton under the microscope, discussing ocean circulation, and the ocean's role in climate regulation. Free choice learning can be extended to focused interaction with crew of specific expertise (e.g., bosun, engineer, cook, navigator, and medic) and the trainee-led development of research projects on STEAMS at SEA voyages.

Along the shoreline, a recorded beach clean may be undertaken alongside searching for shark and ray egg cases, commonly known as mermaid's purses. Both are citizen science projects for the Marine Conservation Society and the Shark Trust UK, respectively and can be readily combined with some other beach activity, such as swimming, relaxing over lunch, or a ball game. This affords playful learning and informal discussions about sources and management of waste; sustainable consumption behaviour; the varied reproductive strategies of sharks, rays, and skates; fishing and consumer choice and the role of top predators in ecosystems. The use of technology, such as an underwater drone and instruments that measure water currents, pH, dissolved oxygen, or the abundance of phytoplankton, allows deeper exploration of physical, chemical, and biological ocean systems, while also engaging young people who are interested in industrial design and engineering.

3.4. Preliminary Study of Impact

For several years, SYF asked trainees to complete pre- and post-voyage questionnaires to gain feedback on training programmes. Most post-voyage questionnaires were completed within two weeks of voyages and can be considered as showing short-term perceptions and outcomes. In addition, written feedback provided deeper insights. The completion of the questionnaires included a declaration of consent to the data being anonymised and used for marketing and research purposes. Informal feedback presented in this article was used with the individual's consent for such purposes.

The data of SYF questionnaires from the years 2023 and 2024 were included in the analysis for this study and comprised of six sections:

1. Asking about confidence in situations, such as meeting new people and working in a team (Likert scale: Not at All, A Little, So So, Quite a Lot, and A Lot);
2. Asking about anxiety about situations, such as climbing heights and taking responsibility (Scale as in Section 1);
3. Asking about their feelings, for example about physical and mental health (Likert scale: Bad, Ok, So So, Good, and Very Good);
4. Responding to statements, for example, "I find it easy to express my thoughts and feelings to others" (Scale as in Section 1, 2024 only);
5. Asking about post-voyage outcomes and reflections, for example, being more interested in ocean science or feeling more self-confident (Scale as in Section 1, 2023 only);
6. Questions to be answered in free text (post-voyage), such as "I really enjoyed…" and "I wasn't happy about…";

To evaluate learner gain, respondents of both, pre- and post-voyage questionnaires were aligned. In 2023, 35 pre-voyage and 33 post-voyage responses to the SYF questionnaire were submitted, with $n = 16$ individuals completing both. Of $n = 67$ pre- and $n = 41$ post-voyage responses in 2024, $n = 18$ individuals matched.

Questions in Sections 1 to 5 were converted into a numerical format (1–5). For Sections 1 to 4, the difference between post- and pre-voyage responses for individuals was calculated in such a way that a shift to a positive outcome is marked by a positive number (learner gain [LG]) and a shift to a more negative response calculated as below zero (negative LG). Answers to questions in Section 6 and similarly formulated questions posed to students by teachers at collaborating colleges in the Plymouth Ocean Science Voyage (2022, 2023, and 2024), as well as informal feedback were considered in the context of intended learning outcomes of ocean-focused STEAMS education on Pelican of London.

4. Findings and Discussion

We are aware that the small sample size in relation to the total number of participants impacts the validity of quantitative data analysis carried out here and therefore, this study is considered strictly preliminary. A research project funded by Sail Training International is developing more comprehensive social research tools for assessing the efficacy of on-board ocean science education, which will be utilised from 2026 onwards.

4.1. Short-Term Learner Gain

The analysis of LG for respondents of questionnaires in 2023 and 2024 (n = 34) indicated that the perceived improvement was strongest in relation to others (outward growth) and nature (downward growth; Figure 1 and Table 1). Responses to "I feel it easy to express my thoughts and feelings to others" and "I feel connected to nature and enjoy outdoor activities" scored the highest average improvements (LG 0.44). Trainees also felt less anxious about taking on leadership roles (LG 0.32) and identified more strongly with the statement "I feel comfortable in social situations and interacting with peers" (LG 0.31), "[I] gained confidence dealing with conflict" (LG 0.24), and their "ability to handle challenging situations" (LG 0.21), indicating that the challenges, outward and upward growth commonly associated with OAE resulted in the development of agency and empowerment (Figure 1).

Table 1. Average learner gains for respondents to Sections 1 to 3 (n = 34, 2023 and 2024) and Section 4 (n = 18, 2024) to pre- and post-voyage Seas Your Future questionnaires.

Section 1: I feel confident about…	Average LG	Section 3: How do you feel about…	Average LG
Meeting new people	0.18	Your mental health	–0.09
Getting on with a group of strangers	0.06	Your physical health	–0.21
Speaking in a group	0.18	Your feelings of happiness	–0.11
Dealing with conflict in a group	0.24	Your feelings of confidence	0.21
Dealing with authority figures, e.g., teacher/supervisor	0.17		
Working co-operatively in a team	0.12		
Understanding other people's point of view	0.06		
Section 2: I feel anxious about…	**Average LG**	**Section 4: How do you identify with these statements…**	**Average LG**
Seasickness	0.33	I feel confident in my ability to handle challenging situations	0.21
Heights	0.27	I often struggle with feelings of stress and anxiety	–0.06
Taking on a leadership role	0.32	I feel comfortable in social situations and interacting with peers	0.31
Meeting strangers	0.21	I find it easy to express my thoughts and feelings to others	0.44
Being in confined spaces	0.31	I feel connected to nature and enjoy outdoor activities	0.44
Taking responsibility	–0.06	I feel supported and understood by my friends and family	0.06
Severe weather	0.30	I have a positive outlook on life and the future	0.06
Lacking ability to undertake tasks	0.03	I feel in control of my life and decisions	0.06
		I struggle with self-confidence and self-esteem	0.19
		I find it difficult to manage my emotions and reactions in challenging situations	0.19

The trainees' self-assessment with respect to parameters external to the sail training environment (e.g., feeling supported and understood by friends and family, a positive outlook on life/future, and mental health, stress, and anxiety) showed little change on average (LG ±0.0x) in the short term. On the other hand, free text responses of some individuals, who started from a position of low scores and had positive LG in almost all elements of the questionnaire indicate significant inward and upward growth (Figure 1) and ocean literacy and marine Identity formation:

> I genuinely can't explain to you how much better I feel now. I feel so positive and joyful, which I haven't felt since childhood. (P., 2024)

> I was able to understand how our actions have a detrimental effect on sea life, providing me with a deeper appreciation of the ocean's fragile ecosystem. (B., 2024)

> The Pelican of London made me feel so special from seeing beautiful sunsets, spirited dolphins playing around the boat and exploring the sea using an underwater camera and I long to feel this feeling again! (L., 2024)

Results show average negative LG (loss) for questions about feelings of happiness (LG = 0.11) and physical health (LG = 0.21). Whether such responses are related to enhanced awareness of self (inward growth) after the voyage or are genuine, long-term negative impacts cannot be discerned here and are particularly important to elucidate and understand using improved and longitudinal research tools.

4.2. Post-Voyage Outcomes and Reflections

The high average score for the statement "I would recommend the voyage to others" of 4.5 (maximum 5.0) indicates high satisfaction with the overall experience (Table 2). It also sets a benchmark, against which other scores may be measured. The personal growth and skills development questions scored slightly higher (3.7 to 4.4) than the aspects related to interest in environmental issues and water-related activities (3.6 to 4.0). Nevertheless, the results indicate raised interest in topics relevant to ocean literacy somewhere between "So So" and "Quite a Lot," with the highest scores given by participants in Ocean Science voyages (caveat: very small sample size).

Table 2. Average response per respondent to Section 5 in the post-voyage Seas Your Future questionnaire from 2023 (n = 33).

Section 5 post-voyage questionnaire	Average score
I would recommend the voyage to others	4.5
I am more confident with others/new friends	4.0
I feel more self-confident	3.7
I have learnt new/more sailing skills	4.4
I am better able to tackle problems	4.0
I am more interested in the environment/climate change	3.6
I am more interested in ocean science	3.7
I have more interest in water-related activities	4.0

Regrettably, only two questions regarding the impact of ocean-focused STEAMS education on trainee interest in environmental topics were included in the SYF questionnaire, and efforts to address this in the current sailing season are underway.

Free text answers in Section 6 of the questionnaire can be categorised into four main categories that relate to the potential for upward, inward, downward, and outward growth (Figure 1):

- Building relationships (e.g., playing games, making friends, and positive encounters with crew);
- Experiencing nature (e.g., being at sea, night sky, sunsets, and seeing dolphins);
- Learning, skills, and knowledge (e.g., teamwork, sailing, and science);
- Leaving the comfort zone (e.g., climbing, snorkelling, being outside, and being with people).

However, this summary hides the general, often exuberant, tone of the free-text answers ("The whole experience was fantastic" and "It was the best opportunity I have ever had"). The aspects of being on board that respondents were not happy about related to a much narrower range of issues, such as seasickness, lack of sleep, sharing, and cleaning bathrooms and a dislike of some fellow trainees. Many responses were simply "N/A."

Answers to the question "Would you tell us how you might use your sailing experience please, your future thoughts and intentions?" demonstrated a shift in thinking that indicates significant personal growth and the development of marine identity and marine citizenship in some:

- Maritime careers (e.g., Royal Navy, marine engineering, and merchant navy);
- Science careers (e.g., ocean science, nature conservation, marine biology, and sustainability);
- Attributes and skills for CV (e.g., teamwork, responsibility, commitment, problem-solving, leadership, and adaptability);
- Personal skills (e.g., building friendships, socialising, communication, conflict resolution, confidence, and listening);
- Sailing (e.g., navigation, knots, and sail-setting applied to recreational sailing);
- Opened horizons (e.g., explore more, travel, breaking glass ceilings, and do new things).

Answers to "How do you think you have changed since the voyage?" confirmed the positive impact the experience had on many with respect to self-awareness, confidence, willingness to take on new challenges (and risks), and exchanging ideas with people, all of which shone through already. Some trainees stated that their anxiety and stress levels have diminished since the voyage. An example for both: "The most significant was learning to live in the present and not allow my nerves to hold me back from pursuing life-changing opportunities" (R., 2024).

Few respondents were unsure or stated that they had not changed. At times, change and a sense of agency may be recognised only with considerable delay, as shown by trainee T. (2022), who did not initially provide feedback, but told their former teacher that the life lessons learned on board contributed to his applying to university in 2025.

4.3. Potential Learning Outcomes of Ocean-Focused STEAMS Education

4.3.1. KSAV Related to Science

Given that KSAV related to ocean-focused STEAMS education are central to this case study and existing questionnaires lack granularity, outcomes for trainees focusing on downward growth for ocean literacy and marine citizenship are examined in more detail. For this purpose, learning outcomes (LOs) proposed by Phillips et al. (2018) for citizen science were modified (Figure 2) and trainee feedback was mapped against them in an attempt to provide a starting point for the development of suitable research tools that evaluate STEAMS-related short- and longer-term outcomes for trainees on Pelican of London. Among these six LOs, four can be considered as instantaneous:

- Questionnaire data indicates that participation in the voyage has raised interest in ocean science and environmental issues, with a number of trainees thinking about pursuing scientific or maritime careers (Figure 2, LO-A).
- Development of self-efficacy related to STEAMS activities or marine citizenship (LO-B) was observed by science leads on board, rather than evidenced through the questionnaires, as it results from practising skills and learning about the nature of science enquiry. Emphasising the interconnectedness of STEAMS subjects and working in interdisciplinary teams are the foundation of training on board (LO-D).
- A different set of questions is required to assess the understanding trainees gain on board (LO-E), but informal conversations and feedback indicate that some trainees of STEAMS at SEA and Ocean Science voyages make progress in this respect.

The remaining two LOs (Figure 2) can only be evaluated with longitudinal studies:

- At times, we hear from teachers that former trainees are pursuing study or apprenticeships in STEAMS subjects (e.g., marine biology, marine engineering, medicine, and physics), evidencing motivation

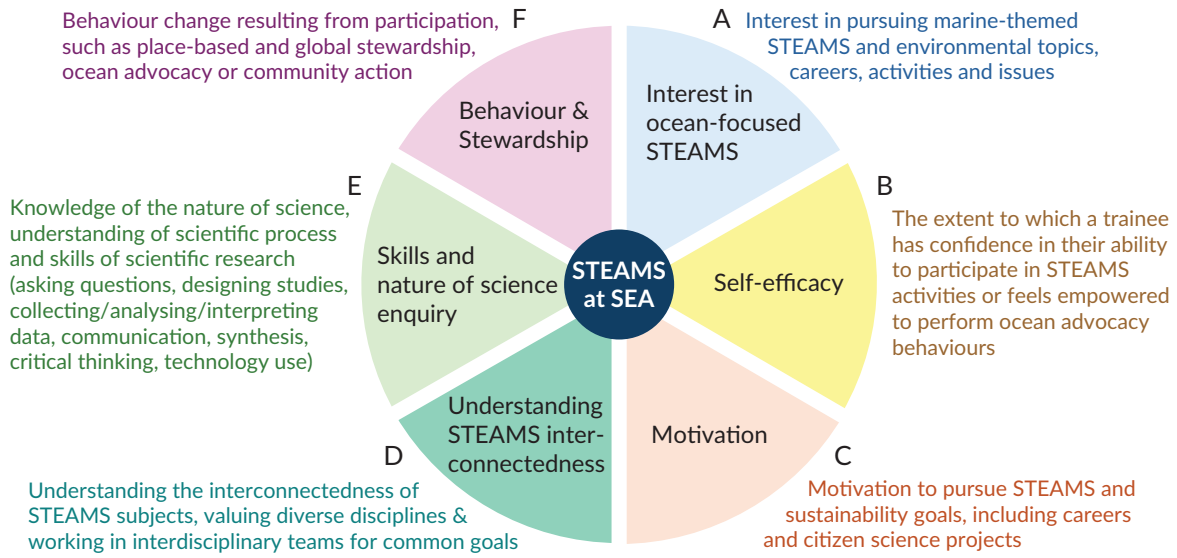

Figure 2. Potential learning outcomes of ocean-focused STEAMS education on sail training vessels. Notes: Based on Phillips et al. (2018, p. 10;used with permission); capital letters refer to the text.

(LO-C). However, more detailed enquiry is needed to ascertain how much this is the result of voyage participation.
- While some participants express intentions to change their behaviour while on board, only follow-up studies can elucidate the longer-term impact on marine citizenship (LO-F).

4.3.2. Deeper Connections

Beyond the personal development and specific science-related gains, some participants indicated having profound positive emotional experiences within the seascape. Many trainees mention that their "favourite thing" is seeing the Milky Way and constellations, watching beautiful sunrises and sunsets, seeing wildlife at close quarters, and discovering bioluminescence at night. Sometimes this was expressed in an almost spiritual nature, suggesting transformative learning at the level of self-actualisation and self-transcendence. Two quotes are exemplary in this respect:

> Later that night the sky was clear and we could see the Milky Way which was fascinating. It really got me thinking about how big the universe is and how small I am compared to it all. It made me realise I could dream as big as I wanted to and there's nothing stopping me in life but myself. Above us was the Starlink satellite and below us were the dolphins swimming through the bioluminescent plankton. (A., 2023)

> I think my most memorable moment was when I was at the helm of the ship, it gave me a sense of purpose and trusted with responsibility. Then, all of a sudden, many dolphins appeared out of nowhere and started jumping out of the water as they swam behind the ship. I felt they were interacting with me, making me part of their world. I was filled with joy and happiness. (K., 2023)

These profound and potentially life-changing experiences are seen to be crucial for developing marine identity and promoting environmental behaviour change and stewardship (marine citizenship).

While this would happen on other sail training voyages, these experiences are being reinforced by strong messages and active participation in ocean-focused STEAMS education. For example, the joy of watching dolphins is transformed into knowledge and understanding by learning how to identify species and collecting data for marine mammal conservation organisations—this represents a synergy between the inward and downward growth dimensions noted in Figure 1. During surveys of two or more hours, wildlife is counted, and identified and parameters pertaining to the ship's and animal movement, their behaviour, and environmental conditions are recorded. The mundane task of scanning the water for sightings becomes part of learning how to conduct scientific data collection with diligence and quality control, and that no sighting is valuable data, too.

5. Conclusion

This study makes a valuable, albeit as yet tentative, contribution to the ongoing efforts in the marine social sciences to explore and promote the following research priorities identified by McKinley et al. (2022): ocean literacy, citizenship and behaviour change, valuing and connecting with the marine environment, and stakeholder engagement and participation. As "total institutions" (McCulloch, 2013; Zurcher, 1965)

comprising a micro-community with limited privacy and no opportunity to absent oneself, vessels demand the development of a convivial mode of existence and self-sufficiency for extended periods and therefore required to make careful choices around consumption (of food, water, and fuel). These represent real-world challenges of resilience and sustainability in a micro-context that provides lessons beyond life onboard. A sailing vessel also provides ample opportunity for intimate engagement with the elemental environment and very different perceptions of space and time, all of which can promote self-reflection, self-actualisation, and transcendence (Reason, 2016).

The preliminary findings of the 2023–2024 season suggest that the STEAMS voyages promote positive learning outcomes in all four dimensions (upward, outward, inward, and downward personal growth). Most obviously, the study is consistent with findings for positive outcomes related to personal/character/resilience and social development (E. Fletcher & Prince, 2017; Hunter et al., 2010; Marshall et al., 2020; McCulloch et al., 2010). What this study highlights more explicitly are the potential positive learning outcomes related to the downward dimension of "knowing about the environment." An explicit, and innovative, focus of the STEAMS voyages is on the development of KSAV in relation to science generally, and marine science specifically. Evidence gathered in this preliminary study suggests that there is real benefit in this respect of the experiential inquiry-based science approach in the context of an authentic engagement with the seascape and the residential awayscape of a sail training vessel.

However, environmental knowledge can also be seen from a more personal, subjective, and affective orientation. Consistent with deeper affective, experiential engagements with the seascape afforded by being on the water for extended periods, particularly under sail, are also reflected in comments made by some trainees. Being immersed more profoundly in elemental forces provided some trainees with arguably transcendent experiences, which are potentially transformative and likely to enhance their development as stewards of the natural world, especially the marine environment.

Perhaps most importantly, the preliminary study provides sufficient, albeit tentative, evidence in support of the anticipated synergies between the more traditional OAE dimension of the voyages and the relatively recent integration of a more overtly inquiry-based environmental science dimension. Together, these combined elements appear to drive development in all dimensions in a mutually reinforcing manner. Thus, it is apparent from the self-report of trainees engaged in the various SYF programmes that their knowledge, attitudes, and identities both towards themselves (self-efficacy, resilience, etc.) and in relation to the marine environment (ocean literacy, ocean citizenship, and identity) have been significantly and enhanced in a manner which is complementary and synergistic. Thus, trainees emerge as more developed and resilient individuals and social agents capable of advocating for the protection and regeneration of the marine environment (ocean sustainability).

It is unfortunate that, to date, these synergies have not represented a major orientation for investigation, and this study represents the first, tentative steps towards addressing this gap. This article highlights the need for a more extensive exploration that can delve deeper into the synergies and can be extended to provide insight as to the longer-term impact of marine science-oriented sail training voyages. This represents an exceedingly fruitful direction for future work and one which will make a valuable contribution to the social marine sciences and efforts to promote much-needed positive human–marine relations.

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Conflict of Interests

Charlotte B. Braungardt works freelance as Head of Science for the sail training organization that operates Pelican of London and Alun Morgan is an Ambassador for Pelican of London.

Data Availability

Data can be made available on request to the authors.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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Ocean Literacy for Ocean Sustainability: Reflections From Australia

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Abstract

Ensuring a sustainable future for the global ocean requires meaningful dialogue and engagement with society. Around the world, efforts to engage and collaborate with society increasingly emphasise ocean literacy as a potential tool for engaging and educating people on ocean issues. A conceptual measure of people's awareness, attitudes, and behaviours towards the ocean, ocean literacy has been highlighted as a key objective in recent ocean sustainability agreements and initiatives, including the UN Decade of Ocean Science for Sustainable Development. In Australia, research and applied interest in ocean literacy is burgeoning. It is therefore timely to take stock and explore recent work that may inform future pathways towards supporting and engaging society in achieving ocean sustainability. Here, we explore examples of ocean literacy research and practice in Australia, to develop prospective thinking on inter/transdisciplinary approaches for advancing ocean literacy under sustainability objectives. In doing so, we anticipate the next steps for progressing ocean literacy in the Australian context, including supporting ocean learning and education, engaging communities at all levels, fostering cross-sector collaboration on connecting people to the ocean, and building strong and actionable policy and funding frameworks to ensure long-term impact. We emphasise the need to collaboratively develop a national ocean literacy strategy to guide and structure these efforts and to establish an Australian ocean literacy coalition to facilitate research, cross-sector collaboration, and implementation in practice.

Keywords

Australia; marine education; marine policy; ocean literacy; ocean sustainability; transdisciplinarity

1. Introduction

Around the world, efforts to engage and collaborate with society increasingly emphasise the concept of ocean literacy as a potential mechanism for engaging and educating people on ocean issues. Ocean literacy reflects people's understanding of the ocean's influence on society and of society's influence on the ocean—and encapsulates people's connection with the ocean, including their awareness, attitudes, emotions, and behaviours (Fauville et al., 2018; Kelly et al., 2022; McKinley et al., 2023). Despite being a conceptual measure, ocean literacy is increasingly presented as a key component to engage and catalyse action in ocean sustainability agreements and frameworks, including the UN Decade of Ocean Science for Sustainable Development (e.g., UNESCO, 2021).

Ocean literacy has evolved from its roots in the education sector (Cava et al., 2005), to become an approach for engaging society in pro-ocean behaviours and actions (McKinley et al., 2023), a global movement (Glithero et al., 2024), and an interdisciplinary field of research (McRuer et al., 2024; Shellock et al., 2024). This evolution of ocean literacy as a concept and practice is expected to continue (Shellock et al., 2024), and it is timely to take stock and explore recent work that may inform future pathways towards engaging and enabling society to achieve ocean sustainability.

In Australia, research and applied interest in ocean literacy is burgeoning: including an expanding education community (Freitas et al., 2022); and a growing focus on ocean literacy research (e.g., Kelly et al., 2022; Shellock et al., 2024), ocean stewardship behaviours (Church et al., 2025; Turnbull et al., 2020, 2021), and policy. Inspired by global initiatives such as the UN Ocean Decade and the broader 2030 Agenda, Australia

has started incorporating ocean literacy into national strategies, emphasising its value towards achieving sustainable ocean management. For example, the draft Australian Sustainable Ocean Plan (Commonwealth of Australia, 2024) outlines a proposed national vision and priorities for managing ocean spaces and marine resources. As such, there is a need to bring relevant stakeholders and sectors together to identify pathways for this engagement and progress towards achieving ocean sustainability.

This perspective article aims to bring together diverse stakeholders to develop prospective thinking on collaborative goals and approaches for advancing ocean literacy under sustainability objectives in Australia. We present views and input from members of a growing Australian ocean literacy community, brought together at the 2024 Australian Marine Sciences Association (AMSA) Conference, held in Tasmania. Three authors (RK, PF, and RJS) chaired a symposium titled Ocean Literacy—Key for Future Ocean Sustainability? which invited input from research on ocean literacy and associated fields, including marine science engagement and education to share insights and approaches, and to critically reflect on ocean literacy theory and practice and its contribution to ocean sustainability. The symposium initiated a dialogue on a vision for ocean literacy in Australia, collated, developed, and presented here.

In this article, we identify current progress, anticipate the next steps, and outline the need for more collaborative and strategic efforts to evolve ocean literacy as a concept, movement, and community of research in the Australian context. We intend for this article to serve as a resource for a wide range of relevant stakeholders, including ocean literacy researchers, practitioners, and marine and environmental decision-makers in Australia and elsewhere. It is anticipated that our reflections will guide the development and implementation of ocean literacy initiatives and inform policy development (at state and federal levels) in the context of ocean sustainability (e.g., Australia's Sustainable Ocean Plan and the forthcoming Australian National Marine Science Plan).

1.1. Positionality

This perspective article brings together views and input from ocean literacy researchers and practitioners from across Australia but does not intend to be comprehensive or representative. We recognise that our own positioning might contribute to our interpretations, i.e., researchers are not separate from the social processes they study (Kaikkonen et al., 2024). As a group, we are reflexive on the ways in which our personal characteristics (e.g., gender, ethnicity, age, nationality, sexual orientation, immigration status, personal experiences, linguistic tradition, theoretical, political, and ideological stances) may shape these interpretations (Holmes, 2020). Hence, we seek to provide a positionality statement (Moon & Blackman, 2014; Secules et al., 2021).

We, the authors of this article, bring a wealth of expertise from across the natural and social sciences (e.g., marine science, social science, education, psychology, and conservation), and beyond the research sector too (including government and NGOs), to contribute to a shared vision of ocean literacy in the Australian context. We represent a variety of career points, though most of us are at early or mid-career stages. The three lead authors are all white and first trained in the natural sciences (marine science and biology) before progressing to interdisciplinary marine research including ocean literacy and related topics. RK and RJS are both European early-career researchers (RK is Irish, RJS is British) who reside in Australia. PF is a mid-career scientist who was born and resides in Australia.

2. Ocean Literacy in Australia

Australia has 13.86 million square kilometres of marine waters, in three of the world's four major oceans, and a coastline of more than 30.000 kilometres. These areas of ocean and coast are also known as Sea Country. Australia's ocean ecosystems are amongst the most iconic (e.g., the Great Barrier Reef, the world's largest coral reef system) and most biodiverse in the world, and are home to more than 33,000 recorded marine species (Trebilco et al., 2021). However, these ecosystems are threatened by human activities including overfishing and pollution (Laubenstein et al., 2023), and the impacts of climate change, e.g., marine heatwaves (Kajtar et al., 2021), and species on the move (Gervais et al., 2021). Further, Australia has the world's third-largest exclusive economic zone and the nation's rapidly growing blue economy contributes $118.5 billion and 462,000 jobs to the economy annually (Department of Climate Change, Energy, the Environment and Water, n.d.).

The majority of Australians (more than 87%) live within 50 kilometres of the coast, approximately 22 million people (Department of Climate Change, Energy, the Environment and Water, 2021). Australians interact with the coast and ocean through their recreation, employment, and cultural practices. Resultantly, strong social and cultural identities linked to the ocean are observed across the country (e.g., Gollan & Curley, 2023). Ocean literacy is touted as a potential catalyst for creating and strengthening these linkages between Australians and the ocean (e.g., Australia's Sustainable Ocean Plan).

2.1. Evolution

The evolution of ocean literacy in Australia reflects a gradual progression, with many initiatives embracing its principles (Figure 1; Cava et al., 2005) and dimensions (Figure 1; Brennan et al., 2019; McKinley et al., 2023) even before the term "ocean literacy" was formally recognised (see Figure 2, for timeline). While the concept gained momentum following the development of the education-focused ocean literacy principles in the US in the early 2000s (Figure 1; Cava et al., 2005), similar ideas were already embedded in Australian marine education and engagement efforts (e.g., Sea Week commenced in 1987; Figure 1). Awareness of the ocean literacy principles grew as Australian marine educators engaged with international networks, particularly through participation in the National Marine Educators Association conferences during the early to mid-2000s. By the 2010s, organisations such as the Marine Education Society of Australasia (MESA) and the AMSA played a pivotal role in promoting ocean literacy across education, research, and policymakers. Today, there are a variety of marine education programs which are underpinned by the concept and practice of ocean literacy—and the education dimension remains the predominant focus of many ocean literacy efforts.

In parallel to the evolution of more contemporary models of ocean literacy elsewhere, which emphasise an expanded and more nuanced approach to ocean literacy (Figure 1; McKinley et al., 2023), in Australia, there is also growing momentum in developing ocean literacy outside of education. For example, this is evidenced by an increasing number of Australian researchers investigating ocean literacy theory and practice (e.g., Arthur et al., 2021; Freitas et al., 2022; Gough, 2017; Kelly et al., 2022; O'Brien et al., 2023). These examples demonstrate the multi-dimensionality of ocean literacy and highlight the complexity of factors influencing human-ocean connections and ocean stewardship behaviours.

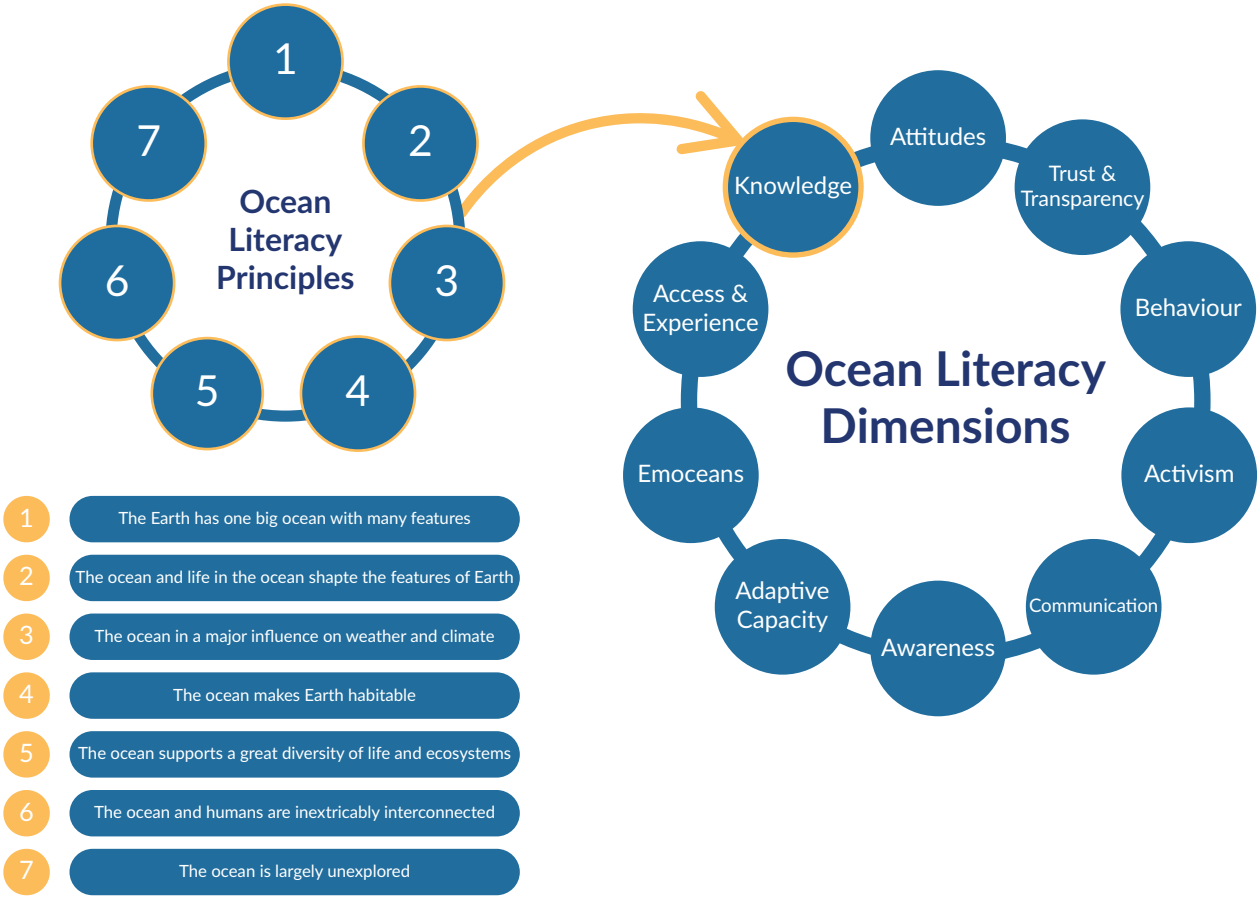

Figure 1. The evolution of ocean literacy frameworks, from 7 knowledge-focused principles (Cava et al., 2005) to 10 dimensions that demonstrate the multi-dimensionality of ocean literacy (Brennan et al., 2019; McKinley et al., 2023).

Increased recognition of ocean literacy has expanded beyond education and research, other sectors have also articulated a need for ocean literacy. For example, the 2023 Ocean Business Leaders' Summit, hosted by Ocean Decade Australia and attended by 257 ocean stakeholders (including First Nations, industry, government, and research), identified ocean literacy as a key enabler of sustainable ocean use through supporting policy and societal change (Ocean Decade Australia, 2023). Decision-making discourse in Australia has also highlighted ocean literacy as a key opportunity for collective national action (Figure 2). The federal government's draft Australian Sustainable Ocean Plan, due for implementation later in 2025, identifies ocean literacy as a catalyst for promoting informed decision-making. The Plan emphasises the importance of elevating ocean literacy through educational programs, resource development, addressing Australia's diverse marine interests, and expanding the blue economy (Commonwealth of Australia, 2024, p. 42).

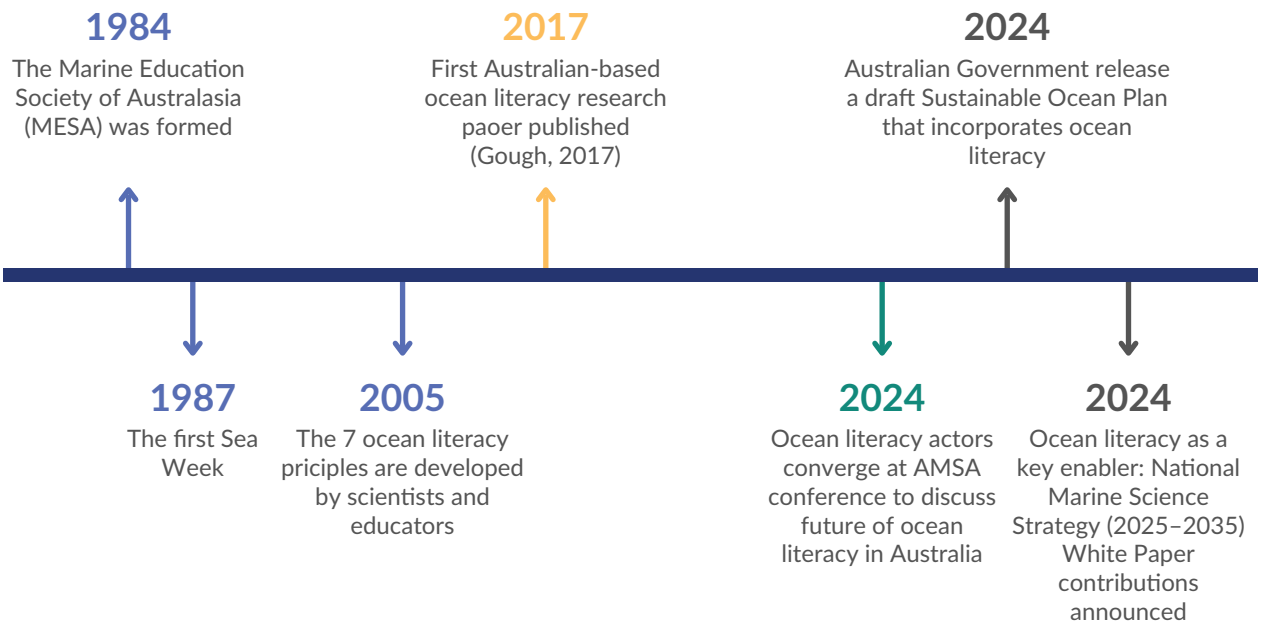

Figure 2. Evolution of ocean literacy in Australia: key milestones from the formation of the MESA in 1984 to the integration of ocean literacy into national strategies and initiatives in 2024. Note: Colour coding represents the following: blue (education-focused), orange (research-focused), dark grey (policy-focused), and teal (bringing the three ocean literacy pillars together: education, research, and policy).

2.2. Current State

Ocean literacy is a rapidly growing cross-sector and interdisciplinary field in Australia, championed by researchers, educators, conservationists, the private sector, and community leaders who aim to connect people with the ocean. The themes outlined in the following sections highlight the multifaceted approaches being used by different groups and sectors to foster ocean literacy and underscore the importance of community engagement and collaboration in progressing ocean literacy. Together, these themes illustrate the breadth and depth of ocean literacy in Australia, showcasing how it is evolving to address local and global challenges. Further, the themes reflect a uniquely Australian perspective on ocean literacy, rooted in the nation's distinct marine environments, such as the Great Barrier Reef and the Great Southern Reef (Bennett et al., 2015).

2.2.1. Ocean Literacy Research

In recent years, ocean literacy research in Australia has expanded across diverse disciplines including marine biology, socio-ecology, philosophy, technology, oceanography (Kelly et al., 2022), marine tourism, environmental psychology (Stoll-Kleemann, 2019), marine social science (McKinley et al., 2022), and marine conservation (McRuer et al., 2025). This may have resulted from the growth of marine social science in Australia, the prioritisation of ocean literacy in horizon scanning exercises (e.g., Herbert-Read et al., 2022; McKinley et al., 2022), and the global and national policy drivers for ocean literacy. This broad range of research fields reflects the multifaceted and interdisciplinary nature of ocean literacy, which combines theoretical and applied research to examine how individuals and communities engage with ocean-related issues (Shellock et al., 2024). These interdisciplinary efforts demonstrate increasing recognition that ocean

literacy is multi-dimensional and extends beyond education alone. Ocean literacy research in Australia has largely been conducted through international collaborations, rather than being exclusively Australia-focused (Paredes-Coral et al., 2021). In comparison with other countries, Australia ranks 11th in number of ocean literacy publications (Shellock et al., 2024). A recent systematic mapping of ocean research across the globe revealed that eight ocean literacy papers have been led by Australian researchers, and seven of these used Australian examples as empirical case studies (Shellock et al., 2024).

One of the first examples of Australian ocean literacy research emerged from an interdisciplinary project, delivered under the Future Seas 2030 initiative (Pecl et al., 2022). The ocean literacy component of Future Seas 2030 sought to identify strategies to improve societal connections to the ocean. To do so, it necessarily brought together expertise from multiple disciplines (including marine ecology, marine socioecology, oceans policy, marine social science, climate impacts, ecosystem modelling, oceanography, environmental communications, psychology, philosophy, public health, maritime logistics, and transdisciplinary science) to identify four drivers influencing and enhancing ocean literacy (Kelly et al., 2022). These drivers—education, cultural connections, technological advancements, knowledge exchange, and science-policy interconnections—each contribute to enhancing public understanding of the ocean, fostering broader societal engagement, and supporting more informed ocean management and conservation efforts (Kelly et al., 2022).

This emphasis on interdisciplinary solutions has also emerged in ocean literacy education research in Australia. Education has become a central focus of ocean literacy efforts in the country, likely due to its direct potential to foster ocean understanding and engagement. However, research has highlighted key challenges such as limited resources, insufficient teacher knowledge, and an overcrowded curriculum, which often hinder the integration of ocean literacy into school programs (Freitas et al., 2022). In response to these barriers, Australian researchers have collaborated with educators to find solutions, including the interdisciplinary and cross-curricular integration of ocean concepts. For example, co-developed ocean education training programs have equipped teachers with the resources needed to incorporate ocean literacy into existing subjects, raising awareness of local marine environments without adding to curriculum overload (Freitas, Venzo, et al., 2024).

Marine science engagement programs and citizen science initiatives also play a critical role in advancing ocean literacy in Australia and several case studies have been described in the literature. Similarly, research on citizen science initiatives like the SealSpotter project demonstrates the effectiveness of public involvement in marine ecological monitoring. Over five years, participants from 23 countries (including Australia) contributed to fur seal counts using drone surveys, underscoring how citizen science can address educational needs, promote ocean literacy, and facilitate data collection in marine systems (Puskic et al., 2024).

2.2.2. Education and Engagement

Building on these efforts, education remains fundamental to fostering ocean knowledge and stewardship values among young people, educators, and the broader public in Australia. While marine science has been included in some state-specific curricula—such as the option for senior secondary students to study marine science governed by the Queensland Curriculum and Assessment Authority—the Australian curriculum lacks a comprehensive and cohesive inclusion of marine and coastal education (Gough, 2017). For over 40 years,

initiatives like Sea Week—led by MESA and later by the Australian Association of Environmental Education—have worked to bridge this gap through nationwide campaigns that promote awareness, knowledge, and community connections to the ocean. However, despite these efforts, progress remains limited due to barriers such as low teacher confidence and an overcrowded curriculum (Freitas et al., 2022). To address some of these challenges, a research initiative by Deakin University implemented teacher workshops aimed at building confidence and capacity to teach ocean-related content (Freitas, Venzo, et al., 2024). Similarly, the education, training, and engagement programs at CSIRO Marine National Facility, empower the next generation of marine experts and equip participants with tools and confidence to deliver meaningful ocean literacy content. Outreach activities, such as the Marine National Facility's Floating Classroom, Educator on Board, and Indigenous Time at Sea Scholarship, target diverse audiences in learning (Arthur et al., 2021).

Informal immersive ocean education programs can also support ocean learning across formal curricula (O'Brien et al., 2023). A recent study revealed that while science is the primary Australian curriculum learning area that informal immersive ocean literacy education programs contribute to, these programs often contribute to other additional learning areas (e.g., sustainability, English, and mathematics), thus highlighting potential cross-curricula opportunities for integrating ocean literacy into formal education, and the potential role informal education programs can play in facilitating such integration (O'Brien et al., 2023).

Informal education programs have made significant contributions to ocean literacy by engaging students and the public outside of conventional classrooms. Initiatives such as the Great Southern Reef Foundation are developing localised, curriculum-linked resources for schools, with over 1,500 users accessing the Foundation's online marine education hub including more than 2,000 people engaging with a single Handfish student worksheet. Similarly, the OceansIQ Ocean Literacy Portal consolidates available ocean literacy resources to make them publicly available online. Established in 2014, and officially launched during Sea Week 2025, demand and interest in this portal are evidenced by the number of website visits, which nearly doubled in the first month post-launch—from 600 visitors between July 2024–February 2025 to over 1,100 in March 2025.

Along Australia's temperate coastline, more than 70 informal education providers offer immersive experiences in marine environments, museums, aquariums, virtual platforms, and discovery centres (O'Brien et al., 2023). For example, the Reef Guardians program initiated by the Great Barrier Reef Marine Park Authority in 2003, has engaged over 350,000 students in actions to protect the reef (Great Barrier Reef Marine Park Authority, 2023). Similarly, the Two Bays education program in Victoria ran for 15 years on a 63-foot catamaran, blending marine science, Indigenous knowledge, and community engagement under the framework of the seven ocean literacy principles. The Australian National Maritime Museum in Sydney, which reaches 6.8 million on-site and online visitors per year (Australian National Maritime Museum, 2024), has committed to a 10-year program associated with the UN Ocean Decade. This includes endorsed exhibitions (One Ocean, Our Future, Ocean Wonders, Ultimate Depth: A Journey to the Bottom of the Sea), collaborative events with communities and industry, and learning programs (e.g., on-site and online plastics programs with The Seabin Foundation and a new ocean ecosystem dynamics course for secondary students).

2.2.3. Storytelling and Communication

In Australia, ocean storytelling is strongly reflected in the lore and traditions of Aboriginal communities, particularly through Sea Country storytelling. First Nations people have long used storytelling as a powerful tool for conveying the importance of marine ecosystems and the practices needed to sustain them; these traditional practices underpin communities' deep cultural connections to the ocean (Reid et al., 2014). The South Coast Seaweed initiative is an example of a contemporary Indigenous-led ocean literacy effort that showcases storytelling and ecological practices, linking traditional knowledge to more dominant Western ocean literacy dialogues.

Communication and storytelling approaches for fostering ocean literacy in Australia can vary widely—from traditional awareness campaigns to picture books to visual media to sophisticated behaviour change initiatives. For example, narrative, non-fiction, marine science-based picture books have emerged as a creative means to promote ocean stewardship among children, whilst also fostering ocean literacy by raising awareness of marine systems, (Freitas, Francis, et al., 2024).

While narrative approaches and visual storytelling are commonly used, their effectiveness in engendering change (i.e., ocean stewardship behaviours and improved ocean literacy) likely relies on the integration of behavioural science principles and carefully designed message elements (de Salas et al., 2022). Research on Great Barrier Reef communication has demonstrated that while messages highlighting the reef's wonder and threats can raise awareness, they must be combined with specific behavioural components to motivate stewardship action (Waters, Losciale, et al., 2024). For instance, recent experimental studies revealed that reef-framed climate messages are more effective at enhancing public engagement with climate behaviours when they include clear calls to action, highlight collective efficacy, and provide tangible pathways for involvement (Waters, Wilson, et al., 2024).

Various organizations across Australia are working to implement evidence-based communication approaches. For example, the Great Southern Reef Foundation uses visual media content to engage with its growing following (1,000+ YouTube subscribers, 9,000+ Instagram followers, 8,000+ Facebook followers, and 3,000+ LinkedIn followers) on pressing marine environmental challenges, such as the deleterious impact of long-spined sea urchins on kelp forests. A recent documentary, *White Rock*, was launched as part of the Ocean Film Festival 2025 (screened at 34 locations nationwide) in tandem with a digital storytelling campaign featuring local fishers, marine scientists, and coastal communities, to further demonstrate human connections to reef ecosystems. Similarly, communication initiatives around the Great Barrier Reef have evolved based on research findings about public engagement. Media analysis of Great Barrier Reef coverage has revealed how different framing approaches and narrative elements influence public discourse and political action (Foxwell-Norton & Konkes, 2022). This growing body of evidence suggests that effective ocean communication must go beyond raising awareness to actively facilitate connections between marine conservation and climate action while providing clear pathways for public involvement in solutions.

2.2.4. Citizen Science

Citizen science is a powerful tool for advancing ocean literacy in Australia, particularly through initiatives supported by the Australian Citizen Science Association, which hosts an online portal listing over

600 programs, including 70 focused on coastal and marine environments. By actively involving individuals in data collection and marine research, these programs enhance public understanding of ocean issues and foster action, aligning with the knowledge, awareness, behaviour, and activism dimensions of ocean literacy (Church et al., 2025; Dean et al., 2018; McKinley et al., 2023). Research has shown that citizen science improves conservation outcomes while also deepening participants' engagement with ocean-related challenges (Kelly et al., 2020).

Notable examples include Coral Watch, the world's largest coral health citizen science initiative, which has been running since 2002 and operates in 135 countries. This program engages participants in coral monitoring by assessing coral colour, a key indicator of bleaching (Marshall et al., 2012). By engaging individuals directly, Coral Watch not only contributes valuable data to researchers but also promotes ocean literacy through its focus on coral health and climate change awareness. Another example is Redmap Australia, which has operated for over 15 years and encourages the public to log sightings of marine species found outside their usual geographic distribution or range. Over 1,500 citizen scientists have logged over 5,000 sightings to date (Redmap pers comms), which provide critical early insights into species' responses to climate change (i.e., evidencing climate-driven changes in the distribution of species, 91% of which had not been detected by scientific monitoring; Wolfe et al., 2025). This engagement has also enhanced participants' understanding of ocean warming and biodiversity shifts: 97% of surveyed participants reported that they trust information produced by the Redmap project (Nursey-Bray et al., 2018; Pecl et al., 2019).

2.2.5. Grassroot and Community-Led Ocean Initiatives

Community-driven initiatives are powerful tools for embedding ocean literacy within the Australian community. Events such as festivals, beach clean-ups, coastal restoration projects, public talks, and interactive outdoor experiences provide place-based opportunities to promote a deeper understanding of the ocean and its interconnectedness with human lives. For instance, the Mandurah Crab Fest and Apollo Bay Seafood Festival celebrate marine culture and ecosystems. Through interactive exhibits, cooking demonstrations, and cultural storytelling, these festivals hold the potential to enhance public appreciation and understanding of the ocean, though this impact has yet to be quantified. Similarly, Clean Up Australia Day, which has engaged over 22 million Australians since its inception in 1990, provides hands-on conservation experiences. This annual event focuses on removing rubbish from local environments, fostering direct action, and community involvement.

However, it's important to note that, to our knowledge, these initiatives do not explicitly follow ocean literacy frameworks, despite the intention to foster emotional connections to the ocean and raise awareness. That said, these activities still create valuable opportunities for diverse communities—including those living inland—to connect meaningfully with the ocean. By fostering emotional connections and raising awareness, such engagement has the potential to drive long-term behaviour change and inspire broader conservation efforts in Australia (Dean et al., 2018). These community actions can ripple outward supporting national policy goals and encouraging sustainable interaction with marine and coastal environments.

2.2.6. Governance and Policy Pathways

Ocean literacy remains in the early phases of policy integration, serving more as an aspirational framework than an implemented strategy. Still, the proposed Australian Sustainable Ocean Plan marks a significant milestone. Due for release later in 2025, the Plan articulates a national vision and national priorities to "guide collective action" on managing ocean spaces and marine resources and emphasises the importance of elevating ocean literacy (Commonwealth of Australia, 2024, p. 42).

Policy strategies developed by the marine science community also increasingly incorporate ocean literacy. For example, the AMSA *Submission on Science and Research Priorities* (https://www.amsa.asn.au/4220/australias-draft-science-and-research-priorities-and-national-science-statement) identified ocean literacy as critical for advancing marine research and supporting sustainable development in Australia. The submission underscores a need to integrate ocean literacy across education, research, and policy to deepen understanding of marine systems, promote stewardship, and strengthen the blue economy. Similarly, the National Marine Science Committee has committed to embedding ocean literacy as an enabler in the next decade of marine science (2025–2035). This commitment aims to position ocean literacy as a guiding framework for fostering public understanding, driving sustainable policy, and ensuring resilient marine ecosystems. Complementing this, the current Future Earth Australia *Our Sustainable Oceans and Coasts National Strategy 2021–2030* (https://www.futureearth.org.au/publications/sustainable-oceans-and-coasts-strategy) highlights a need to support grassroots initiatives that build community trust and promote local stewardship, with improved ocean literacy as a key outcome. Although nascent, these developments represent progress and a growing recognition of the need to embed ocean literacy in actionable policy moving forward.

3. Next Steps for Ocean Literacy in Australia

As outlined in the previous sections, interest in and development of ocean literacy is increasing in Australia. This progress has largely occurred within different sectors (i.e., education, engagement, research, and policy) with little integration to date. However, achieving the goal of ocean literacy—ocean stewardship and sustainability—demands cross-sectoral, collaborative approaches to developing ocean literacy (Shellock et al., 2024). In this section, we articulate our shared aims to contribute to fostering a multi-dimensional culture of ocean stewardship in Australia, and to supporting an Australian society that values and actively works to protect its marine ecosystems. We emphasise the need for a national agenda on ocean literacy to guide and structure these efforts, and a national ocean literacy coalition to facilitate research, cross-sector collaboration, and implementation in practice.

3.1. Progressing Ocean Literacy as an Approach, Movement, and Field of Research

3.1.1. Education

Although ocean literacy has expanded from its education origins, the role of education in advancing people's understanding and connections to the ocean remains salient (Glithero et al., 2024; McKinley et al., 2023). In the first instance, embedding ocean literacy in formal education via curricula is a need and opportunity for advancing ocean literacy in Australia—which could model mandates implemented elsewhere, including the

city of Santos, Brazil, which established ocean literacy as a public policy in its school curriculum in 2021 (UNESCO, 2021). The existing Australian curriculum already provides multiple entry points to incorporate ocean literacy, particularly within learning areas such as the arts, mathematics, chemistry, and biology (Freitas, Venzo, et al., 2024; O'Brien et al., 2023). However, accessing this opportunity will require integration across multiple disciplines in primary and secondary level curricula on a nationwide scale, as well as cooperative efforts between diverse stakeholders, including but not limited to educational institutions, policymakers, curriculum developers, the teaching community, and others such as informal education providers (Santoro et al., 2022).

In addition, teacher training and ongoing professional development are critical for embedding ocean literacy in classrooms. If ocean literacy is to be delivered across the key learning areas of the Australian curriculum, then there is a need to equip pre-service and in-service educators with resources, skills, and support for effectively integrating ocean literacy into their practice. Key challenges to this delivery include recognising and addressing the difficulties educators already face, i.e., an overcrowded curriculum, gaps in knowledge, and training related to ocean education, and poor awareness of the availability of relevant educational resources. This progress is already happening, for example, the Great Southern Reef Foundation has responded to the articulated need to support New South Wales schools and teachers to incorporate ocean literacy into their teachings by developing educational resources that support student learning and teacher capacity-building. These resources adopt a multidisciplinary approach, emphasise place-based learning, and are adaptable to various educational settings and year levels. Reflecting evolving evidence on ocean learning, these resources focus on place-based education and fostering deeper connections between students, educators, and their local marine and coastal environments.

Engagement beyond formal education is also central to progressing national-scale ocean literacy. Efforts should extend beyond school-based education to engage adults, including state and federal decision-makers and business leaders, through outreach and communication strategies that highlight the relevance of the ocean and its resources to their interests. For example, the Australian-led Tuna Champions is an outreach and educational program that provides resources on best-practice fishing for recreational fishers that promote stewardship behaviours. Programs such as these may also support peer-to-peer adult learning opportunities which in turn, may facilitate knowledge brokering through exchange of expertise, experiences, and best practices (Tuohy et al., 2024).

Educational frameworks evidence that learning can occur via diverse experiences that can include informal experiential learning as well as formal learning. Community-centred approaches, which amplify community voices and reflect on-ground context, may be better suited for facilitating experiential learning and encouraging place-based relationships with local marine environments (e.g., via coastal cleanups, citizen science, etc.). These informal experiences are likely to enhance the connection between ocean knowledge and action by linking ocean literacy (i.e., knowledge, attitudes, and behaviours) to conservation and sustainability outcomes. The success of programs such as Reef Guardians shows how more integrated approaches to education and conservation activities can foster both understanding and action across society (O'Brien et al., 2023).

Working with communities to understand what they know, understand, and value about the ocean is needed for developing relevant and engaging ocean literacy education programs. A recent ocean literacy survey

conducted as part of the inaugural Ocean Photographer of the Year exhibition at the Australian National Maritime Museum asked visitors, "How has the ocean changed you?," and "What would you change for the ocean?." With over 8,000 responses received, these data are now proving key to understanding baseline visitor ocean knowledge and assisting museum staff to generate future programming that is fit for purpose (Wright, 2024).

3.1.2. Engagement

In Australia, community engagement is a central pathway for advancing ocean literacy, particularly through initiatives that foster direct connections between people and (local) marine environments. These efforts should build on evidence-based behaviour change insights, to thoughtfully integrate educational components with practical actions, and to translate awareness into sustained pro-environmental behaviours (Kelly et al., 2022). For example, successful models of engagement (i.e., Coral Watch and Redmap Australia), demonstrate how hands-on participation can enhance participant understanding and stewardship (Marshall et al., 2012; Pecl et al., 2019). Examples of evidence-based messaging and communication strategies (e.g., for the Great Barrier Reef) highlight how collective efficacy and public-sphere calls to action encourage engagement in protection actions (Waters, Wilson, et al., 2024). Further, recent Australian research evidence shows that ocean stewardship behaviours can be encouraged by combining nature-based experiences with social interactions through engagement in citizen science programs (Church et al., 2025). Engagement initiatives can be supported by communication campaigns that use traditional and digital media platforms to reach diverse groups and demographics across Australia (Arthur et al., 2021).

Engaging cultural connections is also central to advancing ocean literacy (Glithero et al., 2024; Kelly et al., 2022); recognising the many diverse perspectives and relationships with the ocean experienced across Australia, and appreciating diverse ocean knowledge and values (McRuer et al., 2025). Cultural connections to the ocean refer to the knowledge, behaviours, and relationships people have with the marine and coastal environments (Glithero et al., 2024). Integrating cultural perspectives and narratives into ocean engagement can enrich these experiences with broader and more inclusive views of the ocean. Recognising cultural connections can also help to foster marine stewardship, as people from different groups and places may feel more empowered if they view it as a part of their identity. For example, many First Nations have been intertwined with marine environments for tens of thousands of years; they evidence the potential for sustainable use and conservation of the ocean that reflects a complex relationship between people and the sea (Fischer et al., 2022). These connections and experiences of Sea Country vary amongst First Nations across the continent, further reflecting the diversity of relationships people have with the sea and the diversity of ways that ocean literacy can be experienced and expressed. Efforts to engage with people from the many different cultures in Australia should acknowledge and celebrate the diversity of relationships with the ocean that are possible (e.g., Allison et al., 2020; Schwerdtner Manez et al., 2023).

Another opportunity for ocean literacy engagement is to connect pro-ocean attitudes and behaviour with climate action. To date, limited research has explored the intersection of both ocean and climate literacy and public engagement with pro-environmental behaviours (e.g., Waters, Losciale, et al., 2024; Waters, Wilson, et al., 2024) and evidence suggests that more is needed to help individuals and communities connect the dots between the two. For example, research has evidenced that though Australians' awareness and concern regarding climate impacts on the Great Barrier Reef is high, many people do not link climate action with reef

protection (Dean et al., 2020). Given the urgency of climate action and the deeply emotional connections many people have with marine environments, bridging the gap between ocean and climate literacy is a critical opportunity to engage broader audiences in climate solutions while advancing ocean conservation goals.

3.1.3. Co-developing Ocean Literacy Research

Ocean literacy research seeks to provide collective insights into the kinds of experiences, approaches, and framings that can enable enhancing people's understanding, connections, and relationships with the oceans (McRuer et al., 2024). These insights can inform shared efforts to enhance ocean literacy, improve awareness, influence pro-ocean behaviours, and potentially influence ocean policy and are particularly pertinent to the Australian context.

The many emerging ocean education and engagement initiatives demonstrate the appetite for improving ocean literacy, and research on understanding and measuring ocean literacy is expanding to inform these efforts (McRuer et al., 2024; Paredes-Coral et al., 2021). To date, however, there is scarce empirical evidence on how to measure and/or effectively enhance ocean literacy. For example, although behavioural components are included in the concept of ocean literacy (McKinley et al., 2023), limited research has specifically examined this aspect. As a result, many claims on the potential for ocean literacy initiatives to engender behaviour change remain unsubstantiated. This may also reflect a focus on the education dimension of ocean literacy to date. To progress the value and impact of ocean literacy initiatives, greater emphasis must be placed on the measurement and evaluation of ocean literacy programs through a multi-dimensional lens, including ocean knowledge, communication, behaviour, awareness, attitudes, activism, emotional connection, access and experience, adaptive capacity, and trust and transparency (McKinley et al., 2023). Further, national-scale baselines on societal ocean literacy are needed to inform future collaborative efforts and strategies on enhancing Australians' connections and behaviours in regard to the marine and coastal environment. These efforts may be informed by multi-dimensional evaluations and assessments conducted at national scales elsewhere (e.g., survey instruments currently being developed in Canada and the UK, *pers comms*).

Further, given international (e.g., UN Ocean Decade) and federal (e.g., Sustainable Ocean Plan) focus on ocean literacy as a potential mechanism for change, there is a role and opportunity for ocean literacy research to support this aim and potential (McRuer et al., 2024). These multidisciplinary approaches emphasise the strength and need for research to collaborate in cross-sector partnerships with educators, decision-makers, government, NGOs, industry, communities, and First Nations people's voices. As ocean literacy in Australia continues to evolve and reflect the multi-dimensionality of the concept and practice, there is a need for proactive interdisciplinary research that can support bridging the 10 ocean literacy dimensions and on-ground ocean literacy practice (e.g., McKinley et al., 2023) with overarching strategy and collective vision.

3.2. Progress at the Strategic Level: Policy and Governance

3.2.1. Australian Ocean Literacy Coalition

A key approach to advancing ocean literacy is by leveraging networks (Pedemont et al., 2024). Several ocean literary networks have emerged in Australia over the last decades, largely through grassroots initiatives since the 1980s (e.g., MESA), and continue to develop and evolve, connecting ocean literacy researchers and practitioners through interest and region-specific contexts (e.g., Tasmanian Marine Extension and Engagement Community of Practice). However, these have occurred largely ad hoc and at small scales. Stakeholders nationally have articulated the need for a national strategic effort to increase ocean literacy (Ocean Decade Australia, 2021). If ocean literacy is to advance across Australia, then such national-scale effort and cooperation will be required to co-develop and share ocean literacy resources and strategies, and to support a purposeful movement towards advancing ocean literacy (e.g., Paredes-Coral et al., 2021).

To this end, we propose the establishment of an Australian ocean literacy coalition, to foster collaboration among diverse sectors, and to support the integration of ocean literacy into policy, education, and community initiatives, together ensuring a more sustainable future for Australia's marine environments. Such a coalition aims to provide a structure for diverse individuals and organisations with a common interest in ocean literacy. The coalition will advance, coordinate, and implement ocean literacy research and practice and work together to achieve shared objectives. The coalition will also enable the exchange of knowledge, resources, and best practices to enhance ocean literacy at all levels of society. The Australian ocean literacy community is already a growing network but currently lacks the governance, structure, and resources needed to deliver our ambitious aim. The primary focus of an Australian coalition will be on co-developing and guiding a national ocean literacy strategy (Figure 3).

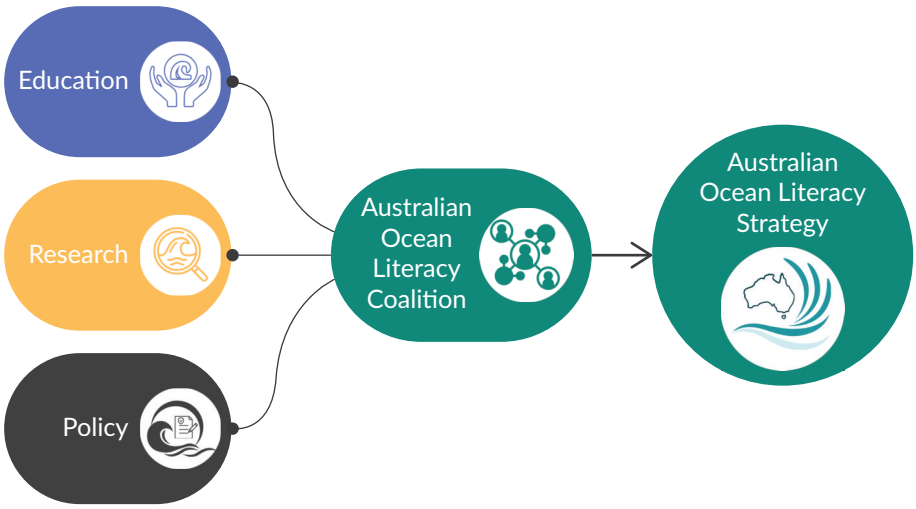

Figure 3. Conceptual framework illustrating three pillars of ocean literacy in Australia: education, research, and policy. Note: The diagram outlines the position and potential role of an Australian ocean literacy coalition, in connecting and facilitating collaboration for co-design and implementation of a cohesive national ocean literacy strategy for Australia.

The UN Ocean Literacy portal will be a valuable resource from which to inform Australian efforts. There are also national-scale examples and lessons to be learned from elsewhere, for example, the Irish Ocean Literacy

Network, which was established in 2016 as an informal network bringing together cross-sector collaborators (including NGOs, public bodies, research, education, private enterprises, and communities) with the shared aim to enhance ocean literacy across the island of Ireland. Since then, this network has expanded and become more formalised, and recently released a Strategic Plan (2024) for enhancing ocean literacy in Ireland. Other examples include the Canadian Ocean Literacy Coalition, an internationally recognised catalyst and hub for ocean literacy collaboration, research, and innovation. Similarly, this coalition evolved when a small network of self-identified ocean literacy organisations recognised the need for a coordinated approach to ocean literacy in Canada and a national ocean literacy strategic plan to guide this approach (Glithero et al., 2018). The coalition has expanded since 2018 and today is a national and international leader in ocean literacy implementation and research. The Welsh Ocean Literacy Coalition was established in 2022 by the Wales Coasts and Seas Partnership, who identified improving ocean literacy as a key focus of their work. Their efforts have included the recent *Ocean Literacy Strategy for Wales 2025* (*Y Môr a Ni*), which articulates a vision and key action areas for building ocean literacy.

The Australian coalition will lead innovative, co-created initiatives to raise awareness and inspire action to protect the ocean and its ecosystems—and to support an Australian society that values and actively works to protect its marine ecosystems. In doing so, we anticipate the coalition will play a pivotal role in driving initiatives that bring together diverse marine stakeholders and perspectives, by fostering interdisciplinary and cross-sector collaboration and providing opportunities for peer-to-peer learning across sectors. Specifically, the national network will create a hub from which to co-develop, and deliver an adaptive national ocean literacy strategy.

3.2.2. National Australian Ocean Literacy Strategy

As aforementioned, there are growing calls for a national Australian ocean literacy strategy amongst the Australian ocean literacy community, and in the research literature (e.g., Freitas et al., 2022). For example, a recent Ocean Decade Australia report evidenced that stakeholder visions for "success" prioritised the idea that government and policy should reflect an improved public understanding of ocean values and threats. A national strategy would act as a framework to enhance understanding and ocean literacy across the national population, as well as within target communities, sectors, and groups. The strategy would also offer opportunity for policy engagement on ocean literacy with the aim of integrating ocean literacy into federal and state-level decision-making and corporate strategies.

In this way, the strategy will facilitate national action to deliver Australia's broader national commitments on sustainable ocean management and marine education—and thus help position Australia as a leader in ocean literacy in forums such as the UN Ocean Decade. The aim of a national Australian ocean literacy strategy is to facilitate ocean literacy knowledge exchange (e.g., supporting peer-to-peer learning across sectors), resource and partnership development (e.g., developing collaborative projects and funding proposals), and policy engagement (e.g., delivering to more integrated approaches to ocean management)—to lead a culture of ocean stewardship in Australia, and to empower an ocean literate Australian society that values and actively works to protect its marine ecosystems (see Box 1). As such, a national strategy will also contribute to engaging Australians on the interrelated themes of climate and environmental literacy.

We anticipate that the national strategy (and the future of ocean literacy in Australia) will be co-developed, following successful examples achieved elsewhere. It will enable ocean literacy to be a cornerstone of achieving ocean sustainability and climate resilience in Australia. The strategy will provide the basis for building federal and state-level policy frameworks and secure ongoing funding for the development and implementation of cooperative, multi-sector ocean literacy programs, which are essential for ensuring long-term ocean sustainability and impact in Australia. For example, we anticipate that the strategy will specifically inform national ocean policy development (e.g., Australia's Sustainable Ocean Plan, National Marine Science Plan, etc.) and help to guide the design and implementation of state-specific marine policies (e.g., New South Wales Marine Estate Management Strategy, Victorian Coastal and Marine Management Plans, etc.). Further, an ocean literacy strategy would facilitate international cooperation and partnerships: for example, with countries such as Canada, Ireland, Wales, and England, who have already established, or are in the process of establishing, national ocean literacy strategies and agendas.

Box 1. Policy priorities moving forward.

1. Establish a national ocean literacy strategy:
    - Develop an ocean literacy strategy that articulates aims for improving ocean literacy in Australia and targets measurable goals (e.g., "By 2050, all Australians will see themselves and engage as stewards of the ocean").
    - Invest in a national ocean literacy office that will coordinate and lead national-scale ocean literacy programs, research, and development.
2. Establish an Australian ocean literacy baseline:
    - Establish an ocean literacy survey program with ongoing funding.
    - Establish a cross-sector national ocean literacy task force to develop and conduct a national-scale multi-dimensional ocean literacy survey.
    - Implement a national-scale survey to determine levels of ocean literacy across demographics in all states and territories.
3. Embed ocean literacy into primary and secondary school curricula:
    - Develop a national framework to integrate ocean literacy across school curricula in an interdisciplinary manner. This framework should align with existing curriculum priorities and learning outcomes, ensuring ocean literacy is embedded through cross-disciplinary connections rather than adding additional content to an already crowded curriculum.
    - Establish professional development opportunities for educators to equip them with knowledge and confidence to effectively integrate ocean literacy into teaching programs.
    - Expand the existing ocean education portal to include resources from all states and territories, creating a centralised national platform to enhance access to ocean literacy learning resources.
4. Develop funding mechanisms for community-led and grassroots ocean literacy initiatives:
    - Establish enduring funding schemes for informal education programs to support ocean literacy engagement and learning in schools.
    - Support local and state-level ocean literacy campaigns that connect communities with local marine and coastal environments.
5. Mandatory corporate sustainability education on ocean-related issues:
    - Mandate that businesses/industries evidence their contributions to ocean sustainability and stewardship dimensions as part of ongoing ESG frameworks and reporting requirements.

4. Conclusion

In Australia, the development of ocean literacy has occurred across different sectors and to date, has included approaches in education, community engagement, policy, and research. However, this development has been limited by poor cross-sector and national-level cooperation, and a lack of policy direction and funding to support continued sector growth. Making progress on advancing ocean literacy nationwide, and contributing to larger-scale objectives for achieving ocean sustainability, will require cooperative and integrated efforts across sectors. For example, by supporting ocean learning and education, engaging communities at all levels, fostering cross-sector collaboration on connecting people to the ocean, and building strong and actionable policy and funding frameworks, in order to ensure long-term impact.

In this article, we have outlined recommendations from members of the growing Australian ocean literacy community, for ocean literacy development, implementation, and research, and thus provide much-needed direction for the continued expansion of ocean literacy in Australia. We invite reflection and development from ocean literacy practitioners and researchers and hope to encourage discussion and action around the priorities identified here. Specifically, we hope these priorities can be useful for federal and state-level decision-makers in their efforts to embed ocean literacy in ocean policies in Australia.

Ocean literacy needs to be advanced across diverse parts of society, including in decision-making, if it is to effectively contribute to ocean sustainability. The key next steps for the growing Australian ocean literacy community are to collaborate with decision-makers at federal and state-levels to develop a national Australian ocean literacy strategy that articulates objectives in alignment with delivering the Australian Sustainable Ocean Plan (currently in draft form); including establishing an Australian ocean literacy coalition. This collaborative perspective article, from members of the Australian ocean literacy community, invites prospective thinking, cross-sector collaboration, and multi-dimensional action on enhancing ocean literacy, with a 2050 vision for all Australians to see themselves and engage as stewards of the ocean.

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Conflict of Interests

This article has provided a descriptive account of the current status of ocean literacy in Australia, to the best of our knowledge. We have cited examples that several of us have been involved with, which do not necessarily represent the national ocean literacy community as a whole. For transparency however, we provide these details here: GP is the Chair of Redmap Australia, JC and LB are co-founders of Ocean Decade Australia, SA is Director of education and impact, CF is a marine science educator at the Great Southern Reef Foundation, JM founded CoralWatch, and PF is a member of the Australian Ocean literacy Reference Group for OceansIQ.

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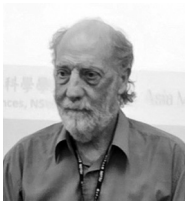

Harry Breidahl has worked in Australia for over 50 years in environmental education as a secondary school teacher, university lecturer, and author. As one of the founders of the International Pacific Marine Educators Network (IPMEN), he is now internationally recognised as a leader in marine education.

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Cut Off by the Tide: How Ocean Literacy Can Help Save Lives

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Abstract

The UN Agenda 2030 promotes safe access to green spaces, and the Ocean Decade aims to enhance humanity's preparedness for ocean hazards and its relationship with the ocean. The tide is not considered an ocean hazard, yet half of the world's coastline is susceptible to tides rising more than two meters in a single tidal cycle and globally >300,000 people per annum lose their lives to drowning. We undertook the first nationally representative survey of public understanding of tide, revealing that over a quarter of the British and Irish public struggled to read a basic tide table. More than one in seven reported having been cut off by the tide, or nearly so. Common misconceptions leading to cut off included the tide coming in much faster and stronger than expected, and often from a different direction. This demonstrates a national failure to understand the variability in tidal movement—one of the most fundamental aspects of the ocean. As the "ocean literacy" agenda advocates for increased access and connection to the ocean, to enable responsible delivery of ocean literacy, it is crucial to understand and increase the public knowledge of tidal variability. This will enable people to enjoy safe access and positive "emoceans" around the rapidly changing, and increasingly risky, marine environment of the future. We suggest considering the addition of a new essential principle of ocean science aiming to improve societal tidal literacy and risk recognition on the coast.

Keywords

beach safety; cut off by tide; drowning; ocean hazard; ocean literacy; tidal cut off; tidal inundation

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1. Introduction

In 2021, an estimated 300,250 people around the world lost their lives to drowning, excluding those attributable to flood-related climatic events and water transport (World Health Organization, 2024). Although the majority of these were due to incidences such as unsupervised children near water or travelling on water, some people lose their lives due to being cut off by the tide along the coastline; exact numbers are not available as the reason for death often remains unknown, e.g., bodies found at sea may be victims of unreported cut off. We do know that between November 2017 and October 2022, the Royal National Lifeboat Institution (RNLI, 2023) in the UK recorded 1,587 incidents of groups cut off by the incoming tide some of whom, without full intervention, could have drowned. Approximately 63% of these were walkers or runners, not beachgoers intentionally playing in, on, or near the sea (RNLI, 2023). In addition, between 2018 and 2022 the RNLI lifeguards responded to at least 2,804 people cut off on beaches without the need to launch a lifeboat (RNLI, 2023) and tidal cut off was the biggest reason for intervention by the National Coastwatch Institution in Wales, accounting for 20% of their recorded incidents to mobilise a rescue that did not always involve the RNLI (National Coastwatch Institution, 2023). To improve safety messaging on beaches around the world, practitioners, beach managers, and safety educators such as the RNLI need to understand the levels of comprehension of tide and what the key issues are that people fail to realise about the tide, leading to the high instances of tidal cut off.

The tide is a complex oceanographical phenomenon that, most simply put, describes the rising and falling (or flood and ebb) of the sea, due to the gravitational forces of the moon and sun. However, tides can vary extensively in their height, speed, and direction of flow depending on many factors, including the phase of the moon, geographical location, local seabed and coastal features, and pressure systems (weather). The difference between the highest and lowest tide in any tidal cycle is called the "tidal range"—with the biggest mean tidal range of 11.7 m in Canada and the smallest in relatively closed waters of the Baltic, Caribbean, and Mediterranean Seas. Davies (1980) notes that approximately half of the world's coastline experiences tidal ranges exceeding 2 m. Macro-tidal (>4 m) and meso-tidal (2–4 m) regions are generally associated with partially enclosed seas and large embayments, such as the UK coastline and the Bay of Bengal. In contrast, micro-tidal regions (<2 m) are typically found along open coasts and fully enclosed seas, including those of southwest Africa and the Mediterranean.

Tidal tidal cut off is the term used to describe when people are cut off from their exit points by the rising tide. There are three common types of tidal cut off recognised by the RNLI: (a) "embayment" cut offs when people are trapped in a bay with no exit points; (b) "sandflat" cut offs, when rapidly filling creeks and channels on undulating sand and mudflats block safe egress from a beach; and (c) "causeway" cut offs, where people walk along a tidal causeway to a rock or islet, and the tide floods the channel back to the mainland (Figure 1). Given the significant tidal variations affecting many densely populated coastal areas, it is important that people understand these basic risks when spending time on the coast.

Both the UN Agenda 2030 and the Ocean Decade recognise the need to provide safe access to green and public spaces (Agenda Goal 11.7; see UN, 2015) and to increase community resilience to ocean hazards (Ocean Decade: Challenge 6; see Pinardi et al., 2024). Although Challenge 6 of the Ocean Decade has so far focussed on preparedness for hazards, education related specifically to hazards and hazard warning systems, it has not yet recognised the need for public understanding of tides and the risks they pose, and it is not currently

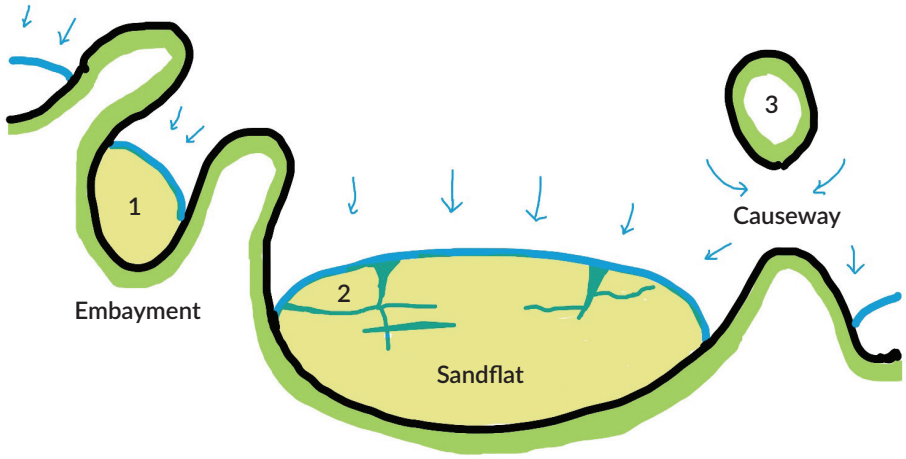

Figure 1. Types of tidal cut off: The three most common ways that people get cut off by the flooding tide.

investing in nurturing basic skills in knowledge or awareness of the tide. In a time when the climate and ocean are changing, with increased risks from more frequent storms and sea level rise, local knowledge of tides is essential to ensuring a safe population (be they visitors to the coast or residents). The 2024 White Paper for Challenge 6 called for capacity building for community resilience, through stronger links between ocean literacy programmes and the ocean hazards community (Pinardi et al., 2024).

Ocean literacy has developed since 2004 from a campaign to provide a framework for informal and formal educators to deliver seven essential principles of ocean science in the US, into a global movement that aims to create ocean-literate global citizens and societies that have "an understanding of the ocean's influence on you—and your influence on the ocean" (National Marine Educators Association [NMEA], 2024, p. 1). These principles—designed originally for early education in ocean science—form the founding stepping stones for all subsequent guidance for ocean literacy practitioners (e.g., Kelly et al., 2022; Santoro et al., 2017), many of whom are working to the broader, evolved concept of ocean literacy for wider society. Ocean literacy is no longer simply about knowledge of ocean science, it is also about people and their behaviour. It is currently accepted that peoples' ocean literacy is affected by at least 10 dimensions, which in turn will result in meaningful behavioural change and action for ocean sustainability (McKinley et al., 2023). Those delivering ocean literacy advocate for increased access, experience and emotional connection to the ocean, whilst decision-makers and researchers call for monitoring the shifting levels of ocean literacy (Ocean Decade Challenge 10 White Paper; see Glithero et al., 2024). However, with increased access comes increased risk: the ocean can be a dangerous place. As ocean literacy practitioners aim to restore people's connection with the ocean through their activities, they may unintentionally increase the risk to life. In turn, any negative experiences may lead to fear of the ocean ("blue fear") which will negatively affect some people's relationship with and behaviour towards the ocean. Currently, the principles of ocean science do not communicate localised variations in tide, whilst the ocean literacy dimensions do not acknowledge the need to build a safe relationship with the ocean. Meanwhile, there is a significant global knowledge gap in people's understanding of how to access coastal space safely.

The seven principles of ocean science were developed by over 150 scientists and educators to be the most important ideas about the ocean that everyone should know. In 2010, this resulted in the publication of 45 fundamental concepts that provided details of each principle, and a detailed scope and sequence guide for

primary and secondary school educators, that includes three specific fundamental concepts related to tide (NMEA, 2010, 2024). Many national curricula do teach the very basics of what causes tide in physics or natural sciences at school, but few (if any) teach the practicality of interpreting this knowledge into safe access to ocean spaces. In Turkey and South Korea, studies with preservice secondary school teachers found common misconceptions of lunar cycles and the moon's effect on tides, and the way teachers described their knowledge was found to be influenced by personal experience and causal observations of the world, rather than taught scientific models (Ogan-Bekiroglu, 2007; Oh, 2014). Finnish secondary school students (14–15 years) and teacher trainees in their first and third years of study had difficulties in understanding the basic principles of tide and in describing the phenomenon of two tidal bulges (Viiri, 2000), which is perhaps less surprising than other countries as there are no significant tidal movements in Finland (Viiri & Saari, 2004). In Spain, the phenomenon of tides is taught from age 10, and researchers have revealed that preservice primary school teachers were not able to interpret the mental models of tides to make predictions in local situations, and have suggested methods to overcome learning difficulties (Armario et al., 2022). So, the evidence from education research suggests that when tidal knowledge is taught formally, its complexity means that it is not always conveyed well to students. Furthermore, few curricula nor the fundamental concepts associated with the seven essential principles of ocean science, include teaching oceanographic variability in local contexts and there is little information on how this translates into risk recognition and coastal safety.

Research that has addressed beach safety often does so specifically concerning rip currents, drowning, and in-water or on-open-water safety. In recent years there has been a rapid increase in interest in beach safety in the peer-reviewed literature. In the Netherlands, researchers revealed that recognition of different coloured beach flag warnings was poor, with the exception of the red flag recognition, indicative of the highest danger levels (Roefs et al., 2023). In Australia, between a quarter and a third of university students admitted that they never or only rarely read beach signage on unfamiliar beaches, and some students misinterpreted key terms when they did read them (Shibata et al., 2024). So what do the public understand and misinterpret about the tide? Although several papers have investigated the knowledge of beach safety, tide, and currents in relation to open or in-water safety, no research could be identified that specifically focuses on being cut off by the tide (from here on referred to as "tidal cut off"). We could not identify one country that has undertaken surveys regarding the public understanding of the tide in relation to risks of tidal cut off.

To address this significant gap, we launched the first nationally representative survey of public understanding and misconceptions of the tide and systematically assessed the public's experience of being cut off by the tide. Through a combination of closed (Likert scale, numerical, or categorical) and open-response questions, with mixed methods analyses, we specifically asked the following research questions:

> RQ1: To what extent are people able to understand tides and apply that knowledge to everyday planning?
>
> RQ2: What are common understandings and misconceptions about the tide?
>
> RQ3: What lessons can we learn from people who have experienced tidal cut off?

Results will inform more effective safety messaging, as well as highlight opportunities for improvements in the ocean literacy agenda that could both save lives and improve people's relationship with the ocean.

2. Methods

As there is no published research, to our knowledge, on what the public needs to know to avoid tidal cut off, we developed a survey that assessed the public understanding of tide and common misconceptions. To gain a comprehensive multi-disciplinary view, the project brought together researchers and practitioners with expertise in the physics of tide (an oceanographer), marine survey logistics (a marine ecologist), rescue (the RNLI), and a specialist in the nuances of language, specifically misconceptions (a linguist).

Our questionnaire comprised 20 questions that used quantitative response categories (mainly numerical, scalar, or categorical), six of which included opportunities to select "other" to explain their answers. In addition, there were three open-response questions encouraging participants to freely articulate their knowledge and conceptions of the tide. Some questions were adapted from Natural England (2023), the Department for Environment Food and Rural Affairs (n.d.), and Armario et al. (2022). The full questionnaire, detailing the origin of specific questions, is available in Supplementary Material 1.

2.1. Data Collection

Data was collected via an online survey instrument that was programmed and disseminated by the Lucid Marketplace–Cint™. The benefit of using a commercial online research panel provider is that it reduces self-selection bias associated with advertising a survey that people may sign up for due to their pre-existing interests, and its dissemination methods support collecting data from a representative sample of the target population. Our survey achieved national representation by age, gender, and region (county) across a sample of 1,300 respondents from Britain and Northern Ireland, and 100 respondents from Éire (Republic of Ireland), reflecting its proportion of the population of the British Isles as a whole. These separate markets were joined for analysis of the data to represent the public understanding of tide for residents of the British Isles.

Ethical approval was obtained from the College of Environmental Sciences and Engineering Ethics Committee (Approval Number: COESE2023LMWCutoffbyTide01, 02/02/2023).

2.2. Quantifying Tidal Knowledge of the General Public

To describe potential factors influencing tidal knowledge, standard questions elicited age, gender, education level, and residency (coastal vs. inland). All respondents were also asked about their personal, family, or household coastal hobbies, frequency of and confidence in reading tide tables, where they access tidal information and if they have ever experienced tidal cut off. Some questions were also added for use by the RNLI, but not analysed in this article. All questions are provided in Supplementary Material 1.

Six core questions were asked to answer RQ1 (To what extent are people able to understand tides and apply that knowledge to everyday planning?), three questions were related to the respondents' basic knowledge of the tide (to confirm whether they understood that there are typically two tides per day and that these tides vary both temporally and geographically), and three questions to test whether they could apply this knowledge to reading and interpreting a tide table in relation to a beach visit. Questions that probed people to interpret the tide table included one basic interpretation of a tide table ("What time is low water?"), one question that was considered of medium difficulty to interpret was which day had the lowest tide for a beach visit, whilst

the most difficult final question related to ensuring a safe return from an island known to be cut off by the tide (presented in results, Table 1).

2.3. Exploring Specific Understanding and Misconceptions of the Tide From Open Survey Responses

To address RQ2 (What are common understandings and misconceptions about the tide?) and RQ3 (What lessons can we learn from people who have experienced tidal cut off?), respondents were asked three open questions to identify common knowledge and misconceptions regarding the tide. People who got specific tidal knowledge questions wrong were asked the reasons that they gave for answering the way they did. All respondents who answered that they had been cut off by the tide, or nearly so, were also asked four open questions about their experience including what they were doing at the time, how the experience has affected their behaviour, and what they tell other people when describing their experience (see Supplementary Material 2, for research questions with associated survey questions).

To specifically understand what people fail to grasp about the tide that results in them becoming cut off, responses to the questions about common understandings and misconceptions were analysed together with the responses describing the experience of tidal cut off (see Supplementary Material 2). Open survey data was imported into an Excel template following methodological principles elaborated by Cotton et al. (2024). Each row was a single participant's response to all the survey questions relevant to the overarching research question (see Supplementary Material 2). Data retained participant unique identifiers and conditions that may be relevant to tidal knowledge (gender Q22, residency Q2, and education level Q23).

To unpick the tidal knowledge and misconceptions of the tide and lessons learned from experiences of tidal cut off, we joined inductive thematic analysis of open responses with more deductive search term analysis, following Cotton et al. (2024) who showed how this combined approach can add insights that may be missed when using only one qualitative analysis approach. Thematic analysis may lead to overlooking less prominent themes, whereas semi-automated search-term-based analysis (e.g., Tenbrink, 2020) can lead to errors such as missing negatives or failing to recognise when comments are inferred or implied; especially nuanced, abstract, or subtle suggestions that cannot be picked up by search term analysis alone. Cotton et al. (2024) suggest using thematic analysis to inform and iteratively develop the list of search terms, yielding a more robust representation of the data via the combined approach that offers increased rigour and transparency (Cotton et al., 2024; Seale et al., 2006). Search term analysis aimed to systematically reflect the respondents' concepts through the larger dataset, firstly across the whole data set for their answers to relevant questions (see Supplementary Material 2), and secondly specifically for those who believe they have been cut off by the tide or nearly so. Those with experience of tidal cut off may have reflections of misconceptions from their experience and may reveal useful advice for others in their responses.

Initial codes were generated during line-by-line reflexive thematic analysis of the answers to all relevant open survey questions. These codes were then categorised (into secondary codes, or conceptual categories) and themed into groups of codes that showed commonality related to the research questions (Braun & Clarke, 2006). Next, search term strings were identified from the initial codes, to represent each conceptual category within each theme (Cotton et al., 2024; Tenbrink, 2020). For example, responses that included words related to the moon or gravity were categorised as "moon's gravitational pull" and grouped into the overarching theme "understanding of tides." Likewise, when respondents used the phrases "same time,"

"morning," "evening," and "dusk," they were categorised as "consistent time of day" and grouped into the theme "misconceptions."

Each search term was placed into a single category and theme, i.e., a specific lexical item only counted as an indicator for one category. As the search was done semi-automatically (in Excel using a formula), search terms were reduced to their root form where appropriate, and care was taken that the automatically detected entries were consistent with the conceptual category the search term belonged to. For instance, the term "bank" was searched without spaces before and after the word, to ensure that both "sand banks" and "sandbanks" could be captured. However, the term " road" had to be coded with a deliberate space before the word, to avoid searching for words that contain the letters "road," such as abroad. Also, some terms like "beach" were used in different contexts, necessitating manual double-checking for each automatically detected instance. Search terms, categories, and themes were reviewed, refined, and adapted by the research team. Their prior in-depth conversations and experience interviewing people who had been rescued by the RNLI helped them understand more cryptic or nuanced terms used by the general public.

Search term analysis aimed to systematically reflect and automatically quantify the respondents' concepts for presentation per category or theme, addressing our research questions (full detail in Supplementary Material 2). The results are presented as the proportion (%) of participants who answered the contributing/relevant questions with a specific category and theme, e.g., % who expressed understanding (theme) related specifically to the moon's gravitational pull (category).

3. Results

In total, we collected responses from 1,429 respondents (1,322 from the UK and Northern Ireland and 107 from Éire). The data were subjected to validation checks, such as excluding nonsensical answers to open questions, which were sometimes combined with repetitive "same" or "don't know" answers to quantitative questions. Approximately 4.5% of the data was deemed invalid, and the remaining 1,368 valid responses were pooled for analysis (1,266 from the UK and Northern Ireland and 102 from Éire). After the validation process, data was confirmed to be nationally representative by age, gender, and region for both the UK and Irish samples. The relative country sample sizes were proportionate to the population figures, allowing us to combine the two country samples for analysis.

Overall, of the 1,368 respondents, 47.6% identified as male and 52.3% identified as female (no respondents identified as other). In total 35.6% of respondents were coastal residents (living within 5 km of the coast), and 64.3% were inland residents (Figure 2). When asked "Do you have any of the following hobbies or interests related to the sea, or regularly undertake any of them for work?," nearly a quarter (23%) responded with no coastal hobbies or interests, whilst 53% had experience of at least one in or on water marine hobby (such as stand up paddleboarding or sailing), 48% included coastal walking as hobbies, and 44% selected spending leisure time at the beach as a personal, family, or household hobby.

To preview our key insights, about two-thirds of respondents demonstrated a basic understanding of the tide, and 15% reported some prior experience of being cut off by the tide. Open responses revealed what the public understands about the tide, but also several common misconceptions that could lead to tidal cut off.

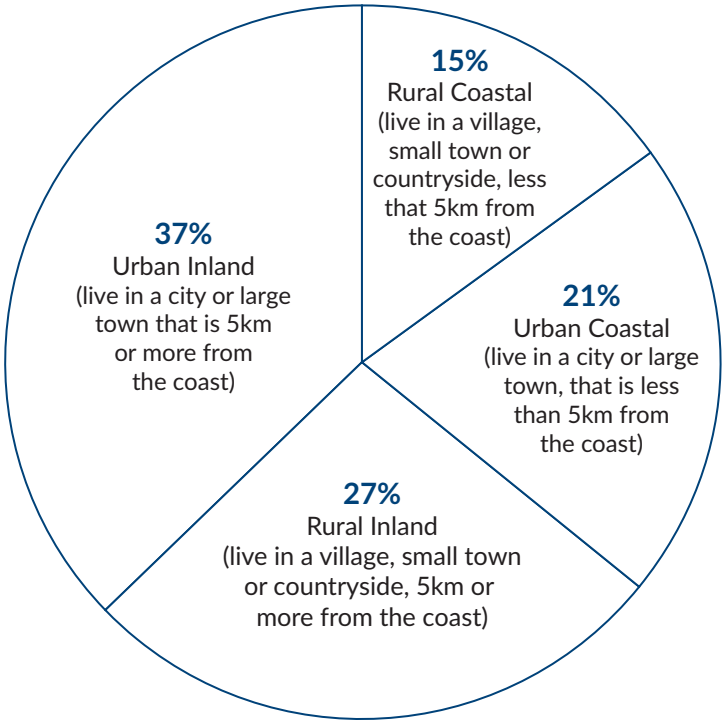

Figure 2. Residency of British and Irish respondents to the tidal literacy survey in relation to the coast (n = 1,368).

3.1. Tidal Knowledge: To What Extent Are People Able to Understand Tides and Apply That Knowledge to Everyday Planning?

When asked "Do you check the tide times before you visit the beach?" 29% of respondents admitted that they never check a tide table before they visit a beach, whilst 22% rarely check a tide table, 31% sometimes check, and only 18% always check a tide table before a beach visit. When asked to select where they access information about the tide, the most popular places to access tide information (n = 968) were the BBC website (37% of respondents), beach signage (35%), and the Met Office (32%), whilst 20% of respondents are also informed by previous experience, and 14% by word of mouth (Figure 3). 10% of these respondents rely solely on previous experience and/or word of mouth for their tidal information (i.e., these respondents did not select any other sources of information). Of the 12% that access information elsewhere, most rely on apps, other websites, and tide books, but some admit they rely on their partners, or they think they can assess the tide when on-site, or that the tidal information does not apply to them unless they are going in the water (e.g., "by looking at it when I get there. I'm generally at the beach to walk the dog, no other activities," or "I don't check as I don't go in the sea").

When asked "How confident do you feel finding information on tide times?" 64% of respondents (71% of men and 57% of women) said that they were somewhat, fairly or completely confident to find information about tide times, leaving 36% of people either not at all confident or slightly confident to find information on tide times. This confidence in finding tidal information is consistent with our finding that 60–64% of people demonstrated basic knowledge about the tide. A higher proportion of respondents identifying as female consistently selected that they did not know the answer when asked the specific tidal literacy questions (Table 1).

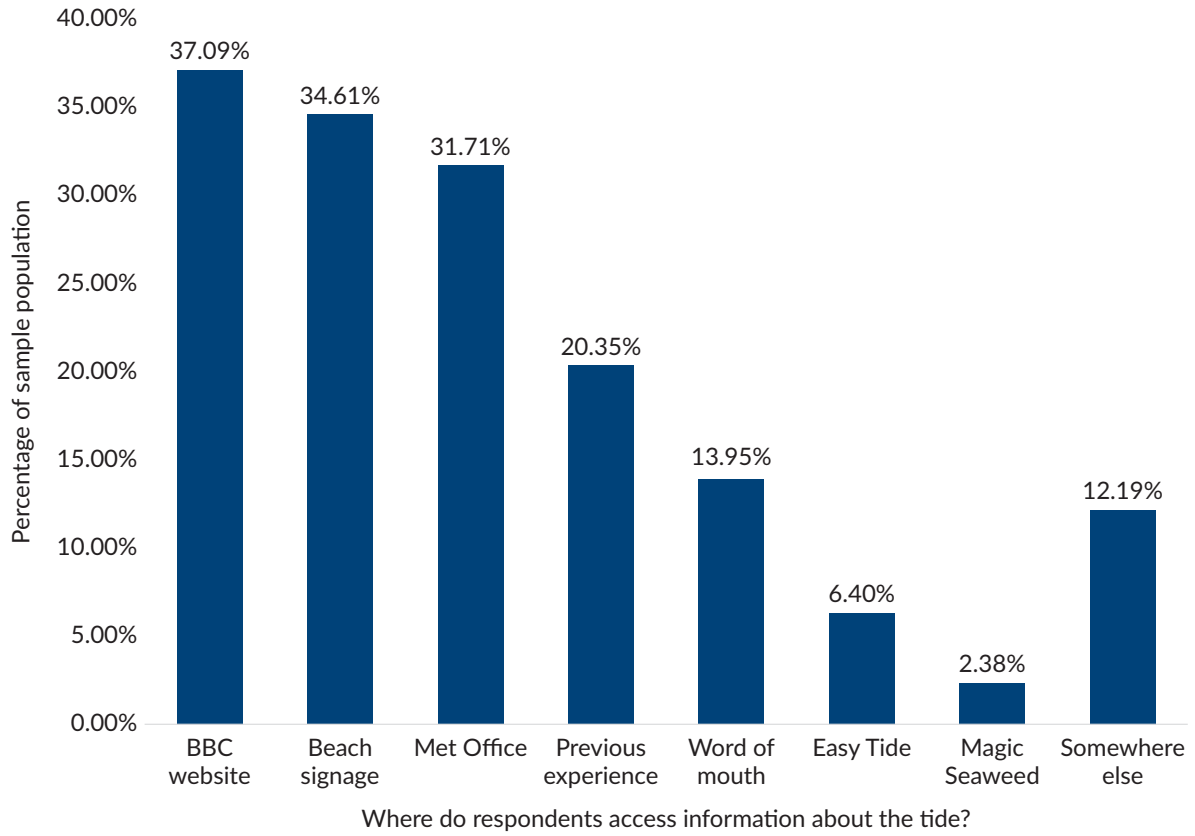

Figure 3. Where British and Irish public access tidal information (*n* = 968).

Table 1. The tidal knowledge of the British and Irish public (*n* = 1,368, from which 47.59% were male (m) and 52.26% female (f).

Q#	Question (correct answer in brackets)	Correct	Incorrect	Don't know
7	How many times does the tide typically come in over a 24-hour period? (2 times)	Total = 62.4% m = 67.8% f = 57.6%	Total = 23.10% m = 22.4% f = 23.7%	Total = 14.5% m = 9.8% f = 18.7%
8	In the same location, are the rises and falls of the tide the same every day? (No)	Total = 60.8% m = 63.3% f = 58.4%	Total = 15.3% m = 16.3% f = 14.4%	Total = 23.9% m = 20.4% f = 27.2%
9	Are the rises and falls of the tides of equal size in all parts of the country? (No)	Total = 64.2% m = 67% f = 61.6%	Total = 5.9% m = 6.3% f = 5.5%	Total = 29.9% m = 26.7% f = 32.9%
15	Basic ability to read a tide table: Look at the BBC Tide Table for Chesil Cove on Christmas Day displayed below. What time is low water? (Select all that apply)	Total = 74.4%* m = 75.9% f = 73%	Total = 14.5% m = 15.8% f = 13.3%	Total = 11.1% m = 8.3% f = 13.7%
16	Medium ability to read a tide table: You would like to spend an afternoon at the beach when the tide is at its lowest. Read the EasyTide tide table below and tell us which is the best afternoon to go.	Total = 42.6% m = 42.8% f = 42.4%	Total = 46.8% m = 47.2% f = 46.4%	Total = 10.6% m = 10% f = 11.2%

Table 1. (Cont.) The tidal knowledge of the British and Irish public (n = 1,368, from which 47.59% were male (m) and 52.26% female (f).

Q#	Question (correct answer in brackets)	Correct	Incorrect	Don't know
18	High ability to read a tide table: You are walking to an island that gets cut off mid-tide on the incoming tide. Read the tide table below. What is the latest time you need to come off the island on each day to return in daylight?	Total = 24.3% m = 26.7% f = 22%	Total = 55.8% m = 56.4% f = 55.2%	Total = 19.9% m = 16.9% f = 22.8%

Notes: * Two low water times were available, and people were scored "correct" if they identified at least one low water time; data shown as % of the total sample; plus m = % who identified as male answering the question this way and f = % of respondents who identified as female answering this way.

When asked "What time is low water? (select all that apply)" based on a BBC tide table, 74.4% of respondents identified at least one correct time for low water (Table 1), whilst less than 33% identified the correct times of both low waters offered to them. Respondents who identified at least one correct low water time were scored conservatively as "correct" in answering the question, as this discrepancy may be due to participants giving the first answer they saw rather than considering further options.

The questions presented in Table 1 were scored as correct (1) or incorrect (0) for each participant. Tidal literacy was the sum of these scores, with a maximum score of 6. Nearly 30% of respondents, representing approximately 30% of the British and Irish public, scored less than average tidal literacy (Figure 4) indicating that they were able to correctly answer fewer than three of six questions about tidal variation or interpretation of a tide table.

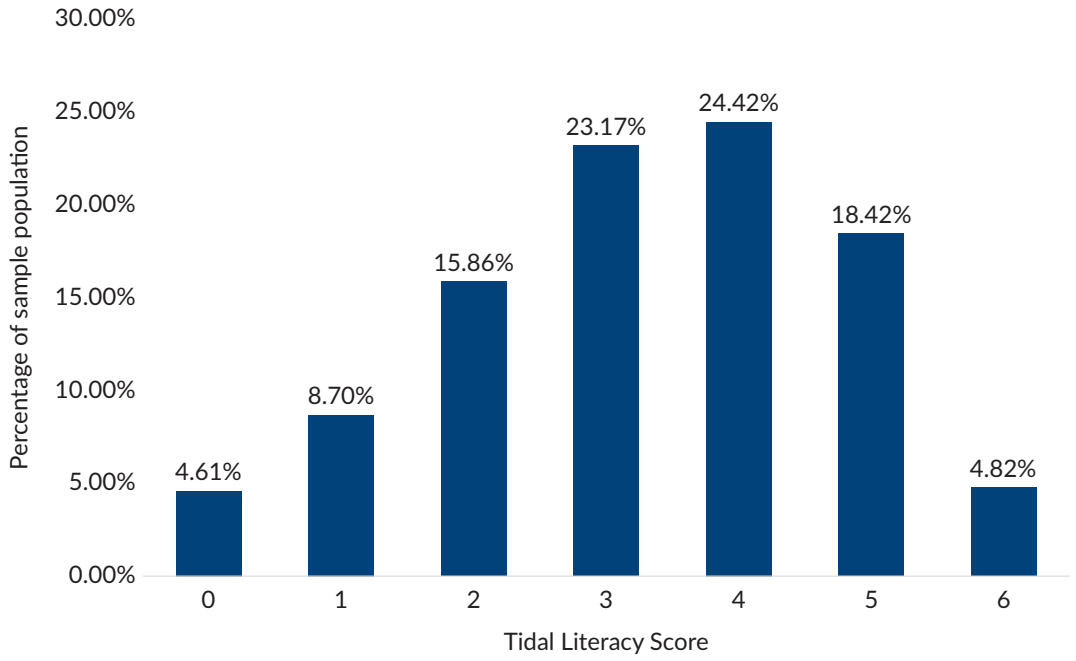

Figure 4. Tidal literacy scores for the residents of the British Isles. Notes: From no awareness of tidal definitions or how to access tidal information correctly (0) to high tidal literacy (6); to score 6, respondents were able to answer six questions about the tide correctly; the average tidal literacy score was 3.29 for 1,368 respondents of a nationally representative sample of the UK, Northern Ireland, and Éire.

3.2. What Are Common Understandings and Misconceptions About the Tide?

Hybrid thematic and search term analysis of open text answers found that over 50% of respondents proved some basic understanding of the tide when asked "Are there any changes (on the coast) that could mean a risk to you as a visitor?" and "What are tides, what do you know about them?" Specifically, 36% of respondents gave answers related to there being high and low tides, 11% mentioned that these tides changed through the day (evidence of the diurnal phenomenon of tides) and almost 20% gave some technical answers referring to the moon's gravitational pull causing the tide (Table 2). 41% of people recognised that the tide was a risk to them or specified that it was a danger. Overall, 8% of respondents wrote that that they had no or minimal understanding of the tide, with a slightly higher percentage of women stating they had minimal understanding.

Table 2. Common understanding and misconceptions surrounding the tide derived from thematic and search term analysis of open responses to the survey of the British and Irish public in 2022.

Theme (TA)/Category (STA)	No. of respondents expressing category	% of possible respondents	% of males expressing category	% of females expressing category
No. of respondents analysed for Themes 1–3	1,368	—	47.7	52.3
TA1 Understanding	812	59.4	63.3	55.7
STA1.4 High and low	497	36.3	37.3	35.5
STA1.1 Moon's gravitational pull	270	19.7	24.5	15.4
STA1.5 Diurnal	161	11.7	14.3	9.5
STA1.2 Water movement	97	7.1	7.8	6.4
STA1.7 Speed	54	4	3.8	4.1
STA1.8 Strength	37	2.7	2.5	2.9
STA1.3 Sea level changes	36	2.6	3.4	2
STA1.6 Spring and neap cycle	19	1.4	1.4	1.4
STA1.9 Otherwise changeable	3	0.2	0	0.4
TA2 Misconceptions	214	15.6	12.4	18.6
STA2.3 Ripples and waves	109	8	6.4	9.4
STA2.2 Currents	50	3.7	2.6	4.6
STA2.4 Consistent time of day	34	2.5	1.8	3.1
STA2.1 Rip currents	19	1.4	0.9	1.8
STA2.6 Other	16	1.2	1.7	0.7
STA2.5 Consistent size/distance/area	4	0.3	0.2	0.4
TA3 Admit minimal understanding	115	8.4	7.4	9.4
No. of respondents analysed for Themes 4 and 5	785	—	47.5	52.5
TA4 Interpretation of Q16a	72	9.12	10.7	7.8
STA4.2 Gave their preferred time	47	6	7	5.1
STA4.1 Judged best time to be the longest period of available beach, rather than lowest tide in daylight	26	3.3	4	2.7
T5 Technical problem with Q16a	13	1.7	1.3	1.9
No. of respondents analysed for Theme 6	1,368	–	47.7	52.3
TA6 The tide is dangerous	560	40.9	39.7	42
STA6.1 Tide as a risk	490	35.8	35.9	35.8
STA6.2 Specifically note danger	117	8.6	6	10.9

Note: Not all respondents answered questions relevant to each theme, as indicated in the table.

However, the results in Table 2 may overestimate the public's understanding of tide. In answer to our question "What are tides, what do you know about them?" at least nine respondents provided very similar definitions of the tide that were almost identical to the first few lines of the Wikipedia definition of "tide":

> Tides are the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the Moon and are also caused by the Earth and Moon orbiting one another. Tide tables can be used for any given locale to find the predicted times and amplitude. (Wikipedia, n.d.)

Two respondents gave the exact same answers as Wikipedia. This raises the possibility that other answers may have been answered by internet searching, rather than reflecting the true participant understanding.

When exploring misconceptions, it is interesting to consider the explanations that the respondents did not give when defining tide or the risk it poses. Less than 10% of respondents mentioned water movement as something they knew about the tide, and less than 5% mentioned the tides' speed, strength, or the fact that the tidal cycle changes by way of spring and neap cycles (Table 2).

Our more detailed thematic and search term analysis across a range of open questions searching specifically for common misconceptions and their distribution among respondents found that over 15% of respondents revealed some misconceptions about the tide (Table 2). Often these involved double-checking the data to ensure whether the search term analysis had identified a real misconception. Common misconceptions included 8% believing that tides were ripples, waves, or tidal bores, 4% expressing that the tide were currents, specifically 1% thought tides were rip currents, and almost 2.5% who believed that the tides appeared at a consistent time of day. For example, "tide comes in in the morning and goes out late afternoon," "when I have been staying by the coast the tides have always been the same time every day, once a day," or "I think they are around 12 noon and 12 midnight."

3.3. What Lessons Can We Learn From People Who Have Experienced Tidal Cut Off?

More than 15% of respondents reported that they had been cut off by the tide, or nearly so, at some point in their lives. Through open responses that described their experience of cut off, half of the respondents revealed what type of cut off they had experienced: 35% were cut off on a sandbank or sand flat, which may have involved creeks backfilling with the tide, almost 10% were cut off on via a causeway, such as a visit to an island, and almost 9% were cut off walking around a headland or cliff to a bay that became cut off (Table 3).

Of the respondents who gave information related to the activity they were undertaking at the time of their tidal cut off experience, 60% were partaking in activities that were intended to be by the side of the water, not in or on the water, and specifically 35% were walking or running along the coast. Of those cut off, 10% admitted that they were distracted by their activities, nearly 8% were somewhere unfamiliar, 7% were either cut off as a child or with children, and 5% acknowledged that they made an error on reading the tide table or got the tide times wrong (Table 3).

The descriptions given by those who had experienced some form of tidal cut off, revealed misconceptions about the tide that led to their cut off. Overwhelmingly, 57% of those cut off noted the speed of inundation,

15% noted that the direction of the incoming tide was different to what they had expected, and 13% noted that the tide was much stronger than they had expected (Table 3).

Three questions unpicked how tidal cut off experience changed the perception of the tide, behaviour on the shore, and messages for other people regarding being cut off by the tide (Supplementary Material 2). 78% of respondents warned of the importance of staying alert and monitoring your surroundings on the beach, often specifically mentioning watching for areas filling around you and blocking your exit route (Table 3). Some (6%) specifically mentioned staying close to your exit point, and away from known danger points. 41% of respondents reiterated the importance of knowing the tide and/or site before visiting the beach, whilst 22% noted that they now respect the tide and advise others to not take risks (Table 3).

Some answers revealed that their experience of tidal cut off had instilled fear towards beach visits, with four people (2%) expressing that they no longer go to similar types of beaches, and three noting that they would prefer to use lifeguarded beaches. These included "I no longer go to the bottom of the cliffs," "I would no longer go across to an island unless I knew the tide had only just gone out," and "I try to be more alert and stay in areas patrolled by lifeguards."

Table 3. Understanding and misconceptions surrounding the tide, and key messages to others from members of the British and Irish public who had been cut off by the tide or nearly so.

Theme (TA)/Category (STA)	No. of respondents expressing category	% of possible respondents	% of males expressing category	% of females expressing category
TA7 Type of tidal cut off	**105**	**50.7**	**44.2**	**56.2**
STA7.3 Sandbank	73	35.3	27.4	42
STA7.2 Causeway	20	9.7	8.4	10.7
STA7.1 Embayment	18	8.7	9.5	8
STA7.4 River	1	0.5	1.1	0
TA8 Activity when cut off	**124**	**59.9**	**61.1**	**58.9**
STA8.1 Walking/running	72	34.8	31.6	37.5
STA8.2 Collecting/foraging/digging/rock pooling/fossil hunting	15	7.3	8.4	6.3
STA8.3 Relaxing/sunbathing	15	7.3	6.3	8
STA8.4 Playing	8	3.9	3.2	4.5
STA8.7 Swimming/paddling	6	2.9	0	5.4
STA8.11 Driving/parking	6	2.9	4.2	1.8
STA8.6 Climbing	5	2.4	3.2	1.8
STA8.8 Fishing	5	2.4	5.3	0
STA8.10 Work	3	1.5	2.1	0.9
STA8.5 Picnic	2	1	0	1.8
STA8.9 Photography	1	0.5	0	0.9
TA9 Links to reasons for cut off	**64**	**30.9**	**28.4**	**33**
STA9.1 Distracted	21	10.1	9.5	10.7
STA9.3 Somewhere unfamiliar	16	7.7	7.4	8
STA9.6 As a child, or with children	14	6.8	6.3	7.1
STA9.4 Human error on tide times	11	5.3	4.2	6.3
STA9.2 Lost/cut off from access point	8	3.9	4.2	3.6
STA9.7 With dog	3	1.5	1.1	1.8
STA9.5 Returned to beach	1	0.5	0	0.9

Table 3. (Cont.) Understanding and misconceptions surrounding the tide, and key messages to others from members of the British and Irish public who had been cut off by the tide or nearly so.

Theme (TA)/Category (STA)	No. of respondents expressing category	% of possible respondents	% of males expressing category	% of females expressing category
TA10 Misconceptions leading to cut off	**171**	**82.6**	**82.1**	**83**
STA10.4 Speed leads to a sudden inundation	118	57	59	55.4
STA10.12 Dangerous	73	35.3	34.7	35.7
STA10.9 The direction of the incoming tide can be different to the expected	31	15	17.9	12.5
STA10.5 Strength	27	13	11.6	14.3
STA10.2 Current	11	5.3	7.4	3.6
STA10.10 Tide times are unpredictable or can be any time	10	4.8	4.2	5.4
STA10.11 Can change with the weather	8	3.9	1.1	6.3
STA10.6 Can be higher than expected	4	1.9	1.1	2.7
STA10.8 Tide is different to the expected	4	1.9	2.1	1.8
STA10.7 Difficult to tell if the tide is coming in out	3	1.5	0	2.7
STA10.3 Creek	2	1	1.1	0.9
STA10.1 Rip current	1	0.5	1.1	0
TA11 How has cut off influenced behaviour or messaging to others	**195**	**94.2**	**92.6**	**95.5**
STA11.5 Stay alert, monitor, and take care, including watch your escape/exit route and areas filling around you	163	78.7	77.9	79.5
STA11.14 It is seriously dangerous!	94	45.4	42.1	48.2
STA11.1 Know before you go (tide and site)	85	41.1	39	42.9
STA11.10 Respect the tide and be sensible/don't take risks	47	22.7	20	25
STA11.7 Know it comes in fast and strong	22	10.6	9.5	11.6
STA11.2 Know when the tide begins to come in or go before the low	12	5.8	5.3	6.3
STA11.4 Stay close to the exit point and away from known danger points	12	5.8	4.2	7.1
STA11.3 Check signage	10	4.8	5.3	4.5
STA11.13 Don't go!	4	1.9	1.1	2.7
STA11.9 Don't fall asleep!	3	1.5	2.1	0.7
STA11.12 Use lifeguard beaches	3	1.5	1.1	1.8
STA11.6 Be aware of creeks filling	1	0.5	1.1	0
STA11.8 Don't be complacent	1	0.5	0	0.9
STA11.11 Take safety precautions	1	0.5	0	0.9

Notes: Of the respondents (N = 207), 45.9% identified as male and 54% as female; themes and categories were derived from thematic and search term analysis of open responses to a nationally representative survey in 2022.

4. Discussion

We undertook the first nationally representative survey of public understanding of tide, reaching more than 1,300 people across the British Isles. Results reveal that over a quarter of the British and Irish public struggle to read and interpret a tide table, and 15% have had personal experience of tidal cut off. Most cut off incidents

described occurred when people were partaking in beach or coastal activities rather than in-water activities, consistent with RNLI's statistics (RNLI, 2023). While simply being distracted from what is happening with the tide is not uncommon, a widespread lack of tidal understanding is clearly identifiable from our data as a root cause of cut off incidents. It stands to reason that these are both related: a better understanding of the varied and sometimes threatening nature of tides would lead to higher alertness, reducing the likelihood of incidents happening due to being distracted. The identified lack of awareness is particularly alarming considering that almost half of our respondents regard coastal walking or spending leisure time at the beach as a hobby. While this interest in coastal pleasures is good news for the ocean literacy agenda, these activities put people at risk.

Basic knowledge of the tide was evident in the quantitative responses to our "tidal literacy" survey questions (three questions about basic tidal characteristics and three about interpreting a tide table). 70% of respondents answered three or more of the questions correctly, indicating that they had basic tidal knowledge and were able to apply it to a tide table and local context in some way. Hybrid thematic and search term analysis of open text responses further revealed aspects of respondents' basic knowledge of tide phenomena, including 36% referencing high and low tides and 20% referring to the moon and/or gravity. Interestingly, more women than men selected that they did not know the answers to the tidal literacy questions, and the same trend was evident in the analysis of open-text responses to explore peoples' understanding of the tide. The fact that men appeared more confident to give answers to tidal questions could give some insight into whether men have unfounded higher confidence levels or whether women are more likely to admit that they do not know, and this could be an interesting area for further work. This knowledge is a novel contribution to the literature, as no other peer-reviewed research could be identified on the public's ability to interpret a tide table or apply this knowledge to a beach visit.

Some work has been done to develop research-based teaching tools to improve the teacher and student understanding of tidal phenomena in Finland (Viiri & Saari, 2004), but gender was not considered in the analysis. Inquiry-based instruction on tides, which integrates archived online data, can also help teachers understand and teach the basic physics related to the tide (Ucar et al., 2011). Although this may increase an understanding of the science behind the tide, little has been done to ensure that this knowledge is taught in a way that can be applied to safe access to coastal spaces. There is evidence that the use of interactive learning tools, such as video simulation in addition to traditional textbook education, can improve learning, but these tools are also known to not overcome students' preconceptions or lived experiences unless their misconceptions are specifically addressed (Ruzhitskaya & Montfrooij, 2011).

The ocean literacy agenda has evolved to recognise that knowledge alone does not always result in logical appropriate behaviours (McKinley et al., 2023), and whilst some of our 1,368 survey respondents do understand the basic physics of the tide, 29% said that they never check a tide table before visiting a beach, and over a quarter could not find low water on a tide table. Of the 968 individuals who told us where they get their tidal information, almost 10% rely solely on previous experience and/or word of mouth, and a few of these people noted that they do not need to check tidal information as they never plan to be in or on the water. This is important, proving that a significant proportion of the public does not understand how to interpret tide tables for safe access, and some cannot see the relevance of or risk from the tide to them as coastal visitors.

So, what are the main misconceptions that lead to 15% of the general public experiencing tidal cut off? The most common misconceptions were seen in the responses from those who had some experience of

being cut off and were related to the speed and strength of the tide, and the direction the incoming tide approached them from. Their experiences led them to warn others to stay alert and monitor their surroundings, specifically to watch their escape routes off the beach and be aware of areas filling around them. 41% of respondents reiterated the importance of knowing the tide and the site, including mention of knowing about local hazards.

Where might people learn about the risk of being cut off by the tide? The fundamental concepts supporting the seven essential principles guide educators on what students should comprehend about ocean science through primary and secondary school (Halversen et al., 2021). Fundamental concept 1C, associated with "Principle 1 Earth has one Big Ocean With Many Features," guides what different grade students should understand about the basics of the tide: from "Tides move water higher and lower, covering and uncovering the shoreline" in the early years to "tides change cyclically relative to the position of the moon, sun and Earth" (Halversen et al., 2021, pp. 17, 59). Countries around the world have started to use the fundamental concepts in their national curriculum, and although we cannot be sure if the UK has engaged with this agenda, our evidence shows that these two fundamental concepts are often understood by the British and Irish public. However, the fundamental concepts were not designed to include the safety implications of ocean science, and as such does not provide information for educators on basic variations where we found the public knowledge lacking: that tides do not occur at the same time every day, that there can be wide variations at holiday destinations, or even along small sections of coast with differing landscapes that change the way the water moves. This is important not just for the citizens of the UK, but also for anybody visiting beaches in different countries or areas where the tide may differ from their previous experience. Notably, on half of the global coastline, the tide can rise and fall over 2 m in 12 hours, which far exceeds standing depth (Davies, 1980).

As the ocean literacy agenda is constantly evolving and now has a strong emphasis on behavioural change to improve our positive relationship with the ocean, there is an opportunity to guide the learning of these variations using the fundamental concepts associated with either Principle 1, where the concept of tide is introduced, or "Principle 6 The Ocean and Humans Are Inextricably Interconnected." Fundamental concepts 6B and 6C, which guide the teaching of Principle 6, detail coastal living and specifically coastal hazards, but the tide is not mentioned as one of those hazards. There is a specific opportunity in Principal 6C5 "Hurricanes, typhoons and tsunamis may adversely affect humans living along or near the coastline" to specify tide, their variations, speed, and strength, as a coastal hazard, and Principal 6C6 that "learning about and preparing for natural hazards can increase survival and minimize the adverse effects of these events" (Halversen et al., 2021, p. 55). Additions to the fundamental concepts here would be beneficial to formal educators seeking detailed curricular guidance.

However, most informal ocean literacy practitioners will guide their activities and content by their own interpretation of the seven essential principles (NMEA, 2010) in combination with the currently accepted dimensions affecting ocean literacy (McKinley et al., 2023). As the ocean literacy movement continues to develop, there are new practitioner toolkits, forums, and practitioner guidance, such as the Ocean Decade Ocean Literacy for All toolkit (Santoro et al., 2017) or the "ten best practise principles for ocean learning communication" (Kelly et al., 2022, pp. 2–3, Appendix B). However, the seven essential principles form the foundation for all of these ocean literacy practitioner guides, which were initially designed for the purpose of teaching ocean-related science more than 20 years ago (NMEA, 2010, 2024). Therefore, it is important that these essential principles can also evolve to fit the new concept of ocean literacy. As the Ocean Decade

agenda seeks to "restore humanity's relationship with the ocean" (Glithero et al., 2024, p. 7) and capacity build towards coastal resilience through a recognised "need for stronger links with the ocean hazards community" and the ocean literacy agenda (Pinardi et al., 2024, p. 34), we propose that improving the understanding of tidal variation in differing local contexts, or simply types of tidal cut off, could be embedded as an eighth essential principle of ocean science—explicitly meeting the ocean literacy agenda's duty of care to ensure safe access for the people it encourages to connect with the ocean, and ensuring uptake from the classroom to the public forum.

Beyond classrooms, for the RNLI as well as for proponents of ocean literacy, our findings raise the question as to how to improve the accessibility and good interpretation of tide and site information and improve uptake of information regarding local hazards. There has been very little peer-reviewed literature on the effectiveness of safety messages specifically aimed to reduce tidal cut off, public understanding of tidal cycles, or how people interpret and apply a tide table to their needs. Beach safety is commonly confused with (in)water safety. Future research needs to decide what safety messaging is most appropriate to improve awareness of cut off risks, including speed, strength, and directions of the tide, and what warning signs to look out for when spending time on the beach. Beach managers and safety practitioners then need to consider the best dissemination pathways and materials suited for recreational users of beaches, who are not in or on the water. Researchers can take some lessons from research into the efficacy of rip current safety messaging. In Australia, targeted education programmes have proved effective at improving international students' knowledge of beach risks, signage, and rip currents (Clifford et al., 2018). In Sydney, interactive learning with teenagers, led by rip current experts that incorporate memorable science of current presentations, was found to increase knowledge and identification of rip currents, but this also led to over-confidence in selecting swimming locations (Brander et al., 2022). Analysis of the reality television show *Bondi Rescue* found that programmes focussing on beach and water safety can influence international audience's understanding of risks, particularly rip currents, and perceptions of who is at risk, but that the messaging should be cautious to not misrepresent the demographics of those being rescued (Warton & Brander, 2017). In the case of *Bondi Rescue*, for instance, there was a heavy focus on rescues of international beachgoers, when they comprise only 10% of coastal drowning incidents (Warton & Brander, 2017). Similarly, place-based reality television programmes could overemphasise local risks that may not apply to the audience's local beaches. In the UK, a similar analysis for effective messaging regarding tidal cut off could be undertaken on the popular television programme *Saving Lives at Sea*, produced by Blast! Productions and aired by the BBC, that follows RNLI rescues.

5. Conclusion

In this article, we introduce the term "tidal literacy" with the definition of "an understanding of how the tide works and how to apply this knowledge to stay safe on the coast, on and in the water." We have demonstrated a deep-rooted national failure to understand the nature of tidal movement, one of the most fundamental aspects of the ocean, and importantly a lack of ability to interpret this information in a local context that involves reading a tide table. Improving societal tidal literacy would not only reduce risk to life but also reduce reliance on water safety and rescues often offered by volunteers in the UK, and support that is not available at all in some countries. As the ocean literacy agenda seeks to "restore humanity's relationship with the ocean" and "capacity build for community resilience, through stronger links with ocean literacy programs and the ocean hazards community," we propose that tidal literacy should be embedded as the eighth essential principle of ocean science. The ocean literacy community has a duty of care to ensure

safe access for the people it encourages to connect with the ocean, something that has already been recognised in the Welsh Ocean Literacy Strategy "Y Môr a Ni" (Wales Coasts and Seas Partnership, 2025). Water safety training is currently commonplace as a cure to being cut off by the tide, or finding oneself in the water unprepared. Improving tidal literacy should be seen as a preventative approach, to ensure safe access to our coast for all, be that in, on, or beside the water—through informal and formal teaching, improved messaging, research, and development of more effective beach signage.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The full survey data set is available on Zenodo (https://doi.org/10.5281/zenodo.15047185)

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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ARTICLE

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The Ocean & Society Survey: A Global Tool for Understanding People–Ocean Connections and Mobilizing Ocean Action

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Abstract

Recent years have seen calls for improved ways of assessing and understanding ocean literacy across a range of contexts. This article presents collaborative advances toward these ends on a global scale, through the co-creation of the Ocean & Society Survey. This Survey—based on national surveys in Canada, Brazil, and the UK—and the collaboration of 20 core partners, aims to capture diverse people–ocean connections. The article outlines the Ocean & Society Survey's objectives to: (a) strengthen people–ocean relationships by exploring

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how people understand, value, and/or engage with the ocean; (b) guide pathways of engagement by identifying behavioural motivations, barriers, and enablers; (c) generate insights to inform targeted, audience-specific ocean communications campaigns; (d) demonstrate the value of transdisciplinary partnerships; and (e) better understand what influences peoples' interests and concerns about the ocean, alongside the willingness and capacity to take action and make informed decisions. The article presents the co-design process of the global tool. In particular, it outlines the analytical approach using thematic, dimensional, and metric indices to compile a question set that can be used to achieve the above objectives by comparing public ocean perceptions over time and across regions. It discusses processes of external review, piloting, and launch in the lead-up to the third UN Ocean Conference, and the projected trajectory until 2030.

Keywords
Ocean Decade Challenge 10; ocean literacy; ocean literacy research; public ocean perceptions; strategic ocean communications

1. Introduction

How we frame global challenges can result in paralysis or mobilization of the action needed to address them. Complex global challenges that span multiple systems and scales have often been framed as "wicked problems" to refer to their nebulous, time-sensitive nature, fraught with competing priorities, interconnected causes, and solutions that often create new challenges (Levin et al., 2012; Rittel & Webber, 1973). Coined by Rittel and Webber (1973) to describe social planning and policy, "wicked problems" have since been applied by a wide range of disciplines, most prominently in the environmental field to describe themes such as sustainability, climate change, and biodiversity loss (Crowley & Head, 2017). Of particular interest to this article, recent literature has pointedly called the issue of restoring ocean health a "super wicked" problem (de Salas et al., 2022), highlighting its complexity and urgency. While such framing underscores the gravity of the challenge, it can inadvertently dampen efforts to mobilize action by presenting issues as too daunting, abstract, or high-level to address. This may result in eco-anxiety (Hogg et al., 2021), or it may cause issues to feel too far removed from everyday life whether due to time, space, probability, or social aspects, known as psychological distancing (Schuldt et al., 2016; Trope et al., 2007). In addition, such framing may distract/detract from efforts that are seeking to drive solutions forward such as the recent Vision 2030 ambition-setting process outlined by the UN Decade of Ocean Science for Sustainable Development (hereafter referred to as the Ocean Decade 2021–2030).

The Vision 2030 process led to the creation of a set of White Papers outlining key recommendations to address 10 Challenge areas within the Ocean Decade framework. Challenges 1 through 6 highlight the need for ocean science solutions related to pressing themes (e.g., marine pollution, biodiversity, climate change, etc.), in tandem with the need for increased technology, data, resources, and infrastructure (Challenges 7–9). Challenge 10 "restoring society's relationship with the ocean," critically focuses on understanding the human dimensions of the ocean that are essential to operationalize all Challenges on a global scale. Drawing on the critical significance of the role of people and society, it is perhaps necessary to reframe the "super wicked problems" facing the ocean as "people-driven problems," underscoring the many ways that ocean health is impacted by human values, attitudes, and behaviours. Moreover, by reframing challenges facing the ocean in this way, pathways for public engagement and people-driven solutions become paramount.

The Ocean & Society Survey is a collaborative initiative by an international and multi-sectoral team of partners to directly respond to recommendations from the Ocean Decade Challenge 10 White Paper (Glithero et al., 2024). In particular, to prioritize increased research and investment in marine social sciences to better understand social dynamics in relation to people–ocean connections and ocean health. The Survey focuses on public ocean perceptions, specifically how people understand, value, and/or engage with the ocean (Bennett, 2016; Jefferson et al., 2015, 2021).

This focus helps to identify behavioural motivations, barriers, and enablers and can thereby help to shape engagement pathways in ways that are reflective of, and responsive to peoples'/communities' experiences (Gelcich et al., 2014). Such an informed approach shifts the traditional science–policy focus on knowledge mobilization of ocean issues, highlighting instead the importance of leaning on public insights to inform science and policy. The Ocean & Society Survey facilitates this shift by asking questions on how people perceive their connection with the ocean-related to their emotions, lifestyle choices, willingness to change habits and behaviours, awareness of ocean benefits, access to the ocean, sources of information about the ocean, perceived ocean threats and concerns, and place-based perspectives on personal and collective actions and solutions. By making the questions accessible to countries around the globe, the Survey fosters the exchange of perceptions related to people–ocean connections and supports public involvement in finding actionable ways to engage society in matters of ocean health (Ashley et al., 2019; Reddy et al., 2017).

The focus of the Ocean & Society Survey on peoples' perceptions of how they understand, value, and engage with the ocean aligns with the evolving concept of ocean literacy (Shellock et al., 2024) and its recent positioning as a societal outcome, i.e., a society that better understands, values, and *cares* for the ocean (Glithero et al., 2024). Although "engage" may be distinguished from "care," with engagement offering a spectrum of ways for people to participate (e.g., the Future Seas Project; Kelly et al., 2022), it is ultimately the lived experiences and place-based dependencies, attachments, and identities that influence engagement (Ardoin et al., 2025). These factors, in turn, shape a broader ethic of care for the ocean (Bender et al., 2022; Buchan et al., 2024; Tugend, 2025). Cumulative research supports this conceptual evolution and public ocean perceptions framing, as signalled by expanding ocean literacy dimensions to better understand and encompass diverse people–ocean connections. The latest ocean literacy dimensions include awareness, activism, communication, attitudes, behaviour (Brennan et al., 2019), emotional connections ("emoceans"), access and experience, trust and transparency, adaptive capacity (McKinley et al., 2023), and ocean connectedness (Fauville et al., 2024). This ever-expanding multidimensional framework enhances the ability to depict the complexity of people–ocean connections. Yet, to conceptualize how dimensions shape—and are shaped by—place and ocean-based realities, we must draw on human experience (Stoll-Kleemann, 2019).

Understanding the significance of how we relate to the ocean requires broader input. This is particularly of note as ocean perceptions research to date retains a knowledge focus with scant attention to social values, emotions, culture, and behaviours (Jefferson et al., 2021). Furthermore, it remains fragmented across disciplines; is geographically skewed toward higher-income countries, and often underrepresents diverse people–ocean connections with an emphasis on ocean threats and protection measures (Lotze et al., 2018). There is a need to further recognize and appreciate the diversity of relationships people have with the ocean. To investigate this, more coordinated, collaborative, and transdisciplinary approaches have been stressed, most recently by the Rio Action Statement during the Fourth Foundations Dialogue Meeting of the Ocean Decade (IOC-UNESCO, 2024). Moreover, responsive research and associated tools are needed to inform

insight-led, actionable solutions and ultimately track progress toward an ocean-literate society (Ashley et al., 2019). The co-creation of the Ocean & Society Survey tool responds to these calls, bridging ocean literacy research with strategic ocean communications, two complementary yet previously parallel fields (Kolandai-Matchett & Armoudian, 2020). It aims to capture public ocean perceptions of peoples' many connections with the ocean to support targeted, audience-specific strategies. This necessary alignment helps to elevate the critical role and focus on society, historically the least invested element within the science-policy-society interface (Balvanera et al., 2020; Pascual et al., 2017).

In what follows, we outline the iterative, 18-month co-design process of the Survey, describing the conceptual, strategic, and methodological stages. We then discuss external reviews, piloting and data collection, validation, data sharing and analysis, and lastly, uptake. We conclude with a discussion on how the findings will help shape collaborative strategies, insight-led communication campaigns, and best practices for public engagement in actionable solutions.

2. Co-Design Process of the Ocean & Society Survey

Between July 2023 and December 2024, 20 core partners and 30+ collaborators from both the Global North and South co-designed the Ocean & Society Survey. The process advanced through three pivotal phases: conceptual, strategic, and methodological. The conceptual phase focused on defining the Survey's purpose and objectives. The strategic phase prioritized the alignment of the initiative with existing efforts to monitor ocean literacy. The methodological phase designed the Survey instrument, ensuring its validity, reliability, adaptability, and accessibility through thematic, dimensional, and metric analyses. Each phase contributed to shaping the Survey as a globally relevant tool.

2.1. Conceptual Phase

From July to September 2023, Survey development was guided by bi-weekly ideation sessions. These sessions included an initial team of 11 ocean literacy researchers and strategic ocean communicators from North America, South America, and Europe. Over the course of Ocean & Society Survey development, team members joined to advance the effort at different stages, resulting in a core team of 20 collaborators by December 2024. The ideation process led to five primary objectives: (a) to strengthen people–ocean relationships by exploring how people understand, value, and/or engage with the ocean over time and across regions (i.e., tracking ocean literacy progress); (b) to guide pathways of engagement by identifying behavioural motivations, barriers, and enablers; (c) to generate insights to inform targeted, audience-specific ocean communications campaigns; (d) to demonstrate the value of transdisciplinary partnerships; and (e) to better understand what influences peoples' interests and concerns about the ocean, alongside the willingness and capacity to take action and make informed decisions.

The Survey was envisioned as an evidence-based and adaptable tool, using accessible platforms and language to be applicable across diverse contexts and audiences. A host institution was necessary to lead the coordination of the evolving process and oversee operations, data security, ethical frameworks, and maintenance. A dedicated website was envisioned to share guiding documents for Survey uptake and open-source access to Survey datasets. Additionally, the role of strategic ocean communications teams was considered key to translating findings into actionable insights for diverse audiences.

2.2. Strategic Phase

The development of the Survey built upon three existing, validated national ocean literacy surveys conducted in 2019 in Canada (Canadian Ocean Literacy Coalition) and 2022 in Brazil (Instituto do Mar, Universidade Federal de São Paulo; and Fundação Grupo Boticário) and in the UK (Department for Environment, Food and Rural Affairs and Ocean Conservation Trust). Each national survey had a distinct focus, but all aimed to better understand public ocean perceptions to track ocean literacy progress. The initial step required a comparative analysis of the national surveys to inform contextualization based on their unique strengths. In Canada, the focus was on fostering relevance through place-based perspectives, ensuring transferability in standardized questions, and promoting inclusivity of multiple ways of knowing the ocean (and the freshwater that flows to it). In Brazil, the emphasis was on integrating ocean literacy and ocean communications into survey design to reach diverse audiences, track changes over time, and develop strategies to increase impact. In the UK, the survey metrics were informed by assessing key ocean literacy dimensions based on the latest research.

2.3. Methodological Phase

Between September and December 2023, the co-design team conducted a comparative analysis of the mentioned national surveys, guided by a methodological approach to assess public ocean perception surveys in Canada (McRuer & Glithero, 2025). This methodology evaluated all questions across the three national surveys based on the following stages: (a) thematic analysis, (b) dimensional analysis, and (c) metric analysis. The purpose of this approach was to identify a core set of questions that would reflect the evolving concept of ocean literacy, informed by the perspectives of any global citizen 18 years of age or older. The analytical process leading to the selection of the core question set leveraged co-design team members' expertise in social science methodologies, questionnaire design and analysis, ocean literacy research and practice, education, psychology, ocean science, and ocean communications. The three stages of analysis are outlined in Subsections 2.3.1–2.3.3.

2.3.1. Thematic Analysis: Identifying Arising Themes in Question Sets

Thematic analysis focused on the Survey question content rather than associated data, using a deductive coding process to attribute a set of nine existing themes (Braun & Clarke, 2022). Themes included ocean connections, ocean health, ocean protection, ocean threats, ocean values, ocean knowledge/awareness, blue economy, ocean governance, and ocean influence and solutions (see Table 1). Themes were assigned to each question across each national survey, allowing multiple themes per question, if applicable. A process of co-review by all team members over four months ensured reliability, given the subjective nature of the analysis. After assigning themes to all questions, the surveys were next combined and organized by thematic representation to discern areas of similarity and difference.

2.3.2. Dimensional Analysis: Assigning Ocean Literacy Dimension(s)

Next, survey questions were evaluated in relation to 10 ocean literacy dimensions put forth in the literature: knowledge, awareness, attitudes, behaviour, activism, communication, emotional connections "emoceans," access and experience, adaptive capacity, and trust and transparency (McKinley et al., 2023; see Table 2). While the analysis of questions for these dimensions was inherently subjective, co-review ensured

Table 1. Themes applied to the analysis of questions from the national surveys.

Themes	Description
Ocean connections	Reciprocal influences (actual or perceived) between humans and the ocean, or references to the physical, emotional, and spiritual relationship(s) with the ocean
Ocean health	Perceptions of ocean health, its importance to daily lives, ocean health priorities, and objectives
Ocean protection	Ocean protection awareness, priorities, strategies, and leadership
Ocean threats	Awareness and concerns related to ocean threats (actual or perceived)
Ocean values	Ocean values related to daily lives, resources, protection, economics, and governance
Ocean knowledge/awareness	Understanding of the ocean and how information is sourced, taken up, and shared
Blue economy	Perceptions and understanding related to ocean-based economic activities, assets, growth, and services
Ocean governance	Perceptions related to processes of enforcement/modification related to ocean and coastal activities, health, and protection
Ocean influence and solutions	Actions, influences, and innovation to support healthy oceans

Table 2. Ocean literacy dimensions used in the analysis of questions from the national surveys.

Dimensions	Description
Knowledge	Knowledge includes both an individual's understanding of ocean topics and their connections, as well as awareness of ocean decision-making, opportunities for participation, and access to relevant information
Awareness	Awareness is the understanding that a problem exists, along with knowledge of possible solutions and actions to address it, which empowers society to take action
Attitude	Attitude involves agreement or concern for a position, shaped by perceptions, values, and views, which can influence policy and societal change
Behaviour	Behaviour involves decisions and actions at all levels, from individuals to institutions, aiming for system-wide change in ocean-related issues
Activism	Activism is the level of involvement in activities aimed at changing policies, attitudes, and behaviours, considering who can participate and the barriers they may encounter
Communication	Communication in ocean literacy includes individual discussions on ocean issues, the effectiveness of information sources, and how organizations convey ocean-related messages to different audiences
Emotional connections "emoceans"	Emotional connections involve the feelings a person has toward ocean-related issues, with all emotional responses, whether positive, negative, or neutral, contributing to potential behaviour change
Access and experience	Access and experience involve both real and virtual interactions with the ocean, while also considering any barriers that may restrict these experiences
Adaptive capacity	Adaptive capacity is the ability to adjust to changes in ocean conditions, including those caused by climate change, economic shifts, or ecosystem alterations
Trust and transparency	Trust and transparency involve confidence in ocean information sources and the clarity of the platforms and processes associated with them

Note: This table has been amended from the original by McKinley et al. (2023).

consistency in coding (Braun & Clarke, 2022). More than one dimension could be attributed to each question. We chose to analyze questions by dimension to ensure that the Survey question set included all. It should be noted that two surveys (Canada and Brazil) were designed prior to the latest iteration of ocean literacy dimensions. While these surveys may not have incorporated dimensions from the outset, all questions across all surveys were found to reflect one or more dimension(s).

2.3.3. Metric Analysis: Assessing Question Alignment With Indicators of Change(s) Over Time

To guide rigorous question selection, each question was considered for its alignment with metric indicators taken from marine ecosystem management literature (Hattam et al., 2015; Link et al., 2010; van Oudenhoven et al., 2012), and chosen for their applicability in the context of people–ocean connections (Burdon, 2020). Chosen indicators included measurability, sensitivity, specificity, scalability, transferability, and policy relevance (see Table 3).

Table 3. Metrics used in the analysis of questions from the national surveys.

Metrics	Description
Measurability	Will data result in something that can be measured?
Sensitivity	Can data reflect change over time?
Specificity	Is the change resulting from a response to a particular ocean literacy dimension or specific to a particular topic?
Scalability	Is the data adaptable to different scales?
Transferability	Is the question applicable across regions?
Policy relevance	Is the question resultant data impactful for policy?

Together, thematic, dimensional, and metric analyses enabled questions to be assessed based on similarities and differences. Guided by the interest to craft a set of representative questions by theme and dimension, 64 potential questions (including 10 demographic questions) were circulated for external review and piloting.

2.3.4. External Review

Between December 2023 and March 2024, the potential question set was circulated with 30+ international colleagues for review, including the IOC-UNESCO's Ocean Literacy Group of Experts (20 members from across diverse disciplines and regions). Feedback was incorporated to clarify misinterpretations, refine content, and remove redundancies. In April 2024, the initiative was shared during the UN Ocean Decade Conference in Barcelona, Spain, during two parallel sessions: first, a dedicated research panel as part of a two-day "Advancing Strategic Ocean Communications Symposium" hosted by Communications INC (a UK based leader in strategic ocean communications) and the Gulbenkian Foundation; and second, an ocean literacy research panel as part of the 5th edition of the Ocean Literacy Dialogues hosted by UNESCO (UNESCO, 2024). Building from this, a collaborative partnership was established between the Canadian Ocean Literacy Coalition (the lead coordinator of the Ocean & Society Survey) and Communications INC (the lead coordinator of the Advancing Strategic Ocean Communications initiative), underscoring the importance of bridging professionals from diverse fields. Moreover, the project's growing interest attracted additional transdisciplinary collaborators. Colleagues with expertise in qualitative and quantitative analysis joined the partner team, offering suggestions to strengthen the reliability and validity of the Survey design.

Between April and July 2024, further review of the proposed question set focused on enhancing data comparison, identifying potential biases in question-wording and answer framing, and offering input for future stages of analysis and audience-targeted reporting.

2.3.5. Reliability and Validity

Reliability is the degree to which an assessment tool produces stable and consistent results. For the Ocean & Society Survey instrument, we use a common psychometric procedure termed test-retest reliability (Mason et al., 2021). This is essentially a measure of reliability obtained by administering the same survey twice over a period of time to a group of individuals. The scores from Time 1 and Time 2 are then correlated to evaluate the test for stability over time (with a test-retest interval of one week).

2.3.6. Piloting and Data Collection Approaches

Between July 2024 and September 2024, the Ocean & Society Survey was piloted in Canada through two modes of administration: (1) facilitated and (2) independent:

1. Facilitated administration maximizes collaborative international efforts and facilitates ease of comparative analysis across countries and over time. Interested countries or groups can join a growing number of countries co-administering the Survey through a public opinion survey agency based in the UK—FocalData. This method provides expedited and nationally representative data collection through existing participant panels and a multi-country dashboard for visualization.

2. Independent administration ensures inclusivity of users without the means to use a public survey agency, or with project-specific goals in mind. Interested countries or groups can access the Survey via a prepared link designed using the REDCap survey platform (affiliated with Dalhousie University), chosen for its accessibility, usability, and encryption standards. Survey links, issued on a case-by-case basis, provide users with secure access to a dedicated page on the REDCap platform for data collection and use.

For both cases, an accompanying guidebook and dedicated webpage (https://oceanliteracyresearch.com/ocean-and-society-survey) support administration by providing background context related to standardization, translation, ethics, contextualization, and open access data sharing. The pilot stage resulted in comparable datasets across the two approaches. Additionally, both approaches provided insight into survey fatigue, language uncertainty, inconsistent responses, lack of attention, and time to completion. Accounting for these factors, between September 2024 and December 2024, the potential question set of 64 questions was refined to 30 (inclusive of 10 demographic questions) primarily consisting of open, ranking, Likert, multiple select, and single select formats—to aid in inclusivity and accessibility on a global scale, additional questions can be added to reflect specific contexts and regions, while retaining the core set for purposes of standardization.

Example questions from the 30-question set are provided in Figures 1–3, drawing attention to motivations, barriers, and enablers of ocean action. The thematic, dimensional, and metric analysis codes (see Tables 1–3) are referenced alongside the question itself. However, depending on the answer choice, additional

dimensions could be further attributed. High-level insights for each example question are provided (based on the Survey results in Canada) to reflect the functionality of specific questions related to how engagement pathways can be tailored and targeted to align with public sentiments. It should be noted that analysis efforts are currently underway at the time of writing, and thus insights provided herein are a snapshot of question-level preliminary analysis. A full complement of insights will be drawn by looking across questions, specific demographics (e.g., gender, age, region), and countries. How the Ocean & Society Survey questions perform in terms of the goal of capturing diverse people–ocean connections will be determined in time, with a more comprehensive analysis forthcoming.

MOTIVATION TO ACT

Question	Answer Choices	Theme(s) Attributed	Dimension(s) Attributed	Metrics Attributed
Why are you willing to change your lifestyle? Please select your top 3 reasons.	1. I like my lifestyle, but am willing to change 2. I know what to do, or am willing to learn 3. I have access to resources to support change 4. I believe I can make a difference and feel motivated to help 5. I find it is convenient and/or affordable 6. I'm concerned about my impact on pollution and climate change 7. I worry about future generations 8. I think ocean health is my responsibility 9. I feel if I don't make change(s), my lifestyle will be negatively impacted (e.g., money, health) 10. None of the above	• Attitudes • Ocean health • Ocean influence and solutions	• Attitudes • Behaviour • Adaptive Capacity	• Measurability • Sensitivity • Specificity • Scalability • Transferability • Policy Relevance

Significance for Engagement Pathways

Worry for future generations, and concern about personal impact on pollution and climate change are the top motivators respondents. Importantly, they also feel they can make a difference and are motivated to help. Examples to support engagement efforts include:

- Framming actions as a legacy for future generations by using storytelling and visuals that connect today's choices with tomorrow's future in positive ways.
- Highlighting personal environmental footprints and showing the impact of small daily changes.
- Cultivating a sense of civic duty, shared norms and responsibility by leveraging trusted communitiy voices to issue call-to-action, and tie participation to community pride.

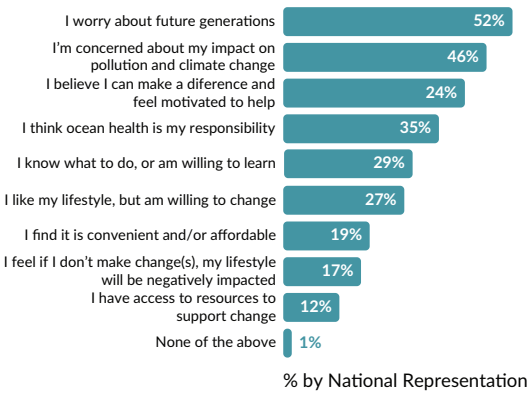

Figure 1. Example question and response from the Ocean & Society Survey (Canada) dataset (January 2025) related to motivation to act, spotlighting attributed themes, dimensions, and metrics, as well as preliminary insights lending to functionality.

BARRIERS TO ACT

Question	Answer Choices	Theme(s) Attributed	Dimension(s) Attributed	Metrics Attributed
Why are you not willing to change your lifestyle? Please select up to 3 reasons.	1. I like my lifestyle and don't want to change 2. I don't know what to do, or am not willing to learn 3. I don't have access to resources to support change 4. I find it is inconvenient and/or expensive 5. I feel unmotivated to help as the issues feel too big 6. I'm not concerned about my impact on pollution and climate change 7. I am willing to learn and/or have the resources to support change, but don't know where to start 8. I think we have to live for today, not worry about future generations 9. I don't think ocean health is my responsibility 10. I think technology will fix any ocean issue 11. I feel if I make change(s), my lifestyle will be negatively impacted (e.g., money, health) 12. None of these	• Attitudes • Ocean health • Ocean influence and solutions	• Attitudes • Behaviour • Adaptive Capacity	• Measurability • Sensitivity • Specificity • Scalability • Transferability • Policy Relevance

Significance for Engagement Pathways

Feeling that issues are too big, a longside lack of motivation, incovenience, or cost, are the most significant barriers for respondents. Yet, their willingness to learn and access to resources suggest strong potential for change. Examples to support engagement efforts include:

- Reducing the perception of scale and inaction by making ocean action feel achievable and personnaly relevant—emphasizing collective impact, showing how individual actions aggregate into real outcomes, and highlighting successful community-led efforts and tangible wins.
- Addressing inconvenience and cost by promoting low-cost, easy-to-adopt behaviours, and framming ocean-friendly choices as pratical, time-saving, or financially beneficial.
- Supporting those willing to learn but unsure how by creating clear, actionable guides and toolkits tailored to different lifestyles.

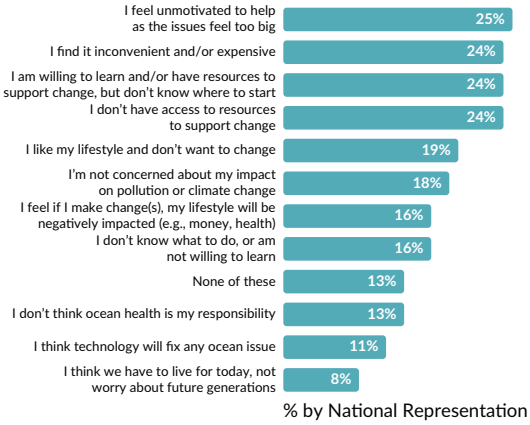

Figure 2. Example question and response from the Ocean & Society Survey (Canada) dataset (January 2025) related to barriers to act, spotlighting attributed themes, dimensions, and metrics, as well as preliminary insights lending to functionality.

ENABLERS TO ACT

Question	Answer Choices	Theme(s) Attributed	Dimension(s) Attributed	Metrics Attributed
Would any of the following incentives encourage you to make lifestyle change(s) to support ocean health?	1. Being provided with government resources and support 2. Feeling that I'm doing the right thing 3. Feeling that I'm helping a team or community 4. Feeling that my lifestyle will be positively impacted (e.g., money, health) if I make lifestyle changes 5. Seeing others take action (e.g., leaders, businesses, influencers, etc) 6. Understanding how my actions affect the ocean 7. Learning about issues in clear and actionable ways 8. Feeling that my lifestyle will be negatively impacted (e.g., money, health) if I don't make lifestyle changes 9. None of these	• Attitudes • Ocean health • Ocean influence and solutions	• Attitudes • Behaviour • Adaptive Capacity	• Measurability • Sensitivity • Specificity • Scalability • Transferability • Policy Relevance

Significance for Engagement Pathways

Respondents feel most willing to help when they feel they are doing the right thing, understand how their actions impact the ocean, and learn in clear and actionable ways. Based on this, examples to support engagement efforts include:

- Appealing to moral clarity and personal integrity by framing ocean-positive behaviorus as morally right and socially responsible, using affirming language that aligns with personal ethics, values and integrity.
- Making impacts visible and tangible by sharing clear, relatable cause-effect stories showing how individual or collective behaviours influence ocean health.
- Proritizing clarity and actionability by delivering information in simple, practical formats making the steps from knowledge to action more achievable.
- Highlighting personal gains by emphasizing the co-benefits of action such as saving money, improving health, or creating more meaningful experiences.

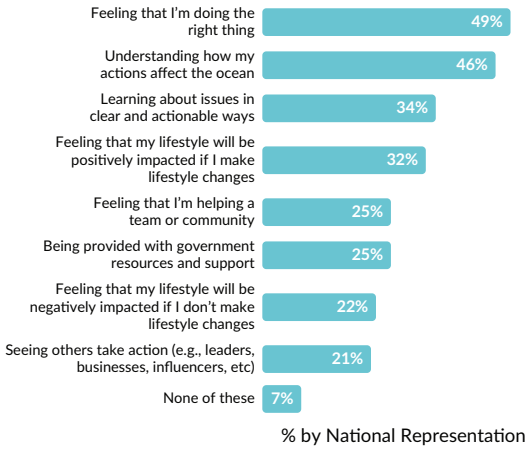

Figure 3. Example question and response from the Ocean & Society Survey (Canada) dataset (January 2025) related to enablers to act, spotlighting attributed themes, dimensions, and metrics, as well as preliminary insights lending to functionality.

2.4. Data Sharing and Analysis

To promote open access to datasets to foster collective learning, cross-regional comparison, and broader impact, users of the Ocean & Society Survey (administered or independent) are encouraged to share their anonymized datasets. Datasets from the facilitated administration of participating countries can be found on the dedicated website (https://oceanliteracyresearch.com/ocean-and-society-survey) with raw data available upon request.

2.5. Survey Uptake

Following 18 months of co-development (see Figure 4), the Survey was launched via facilitated administration in January 2025, starting with Canada (Canadian Ocean Literacy Coalition). This was quickly followed by the US (National Marine Educators Association), Brazil (Group Boticario Foundation), the UK (Ocean Conservation Trust), Norway, Ireland, Spain, Bulgaria, Cyprus, and Finland (EmpowerUs group), Sweden (Swedish Institute for the Marine Environment, University of Gothenburg and Voice of the Ocean), and France (EU4Ocean).

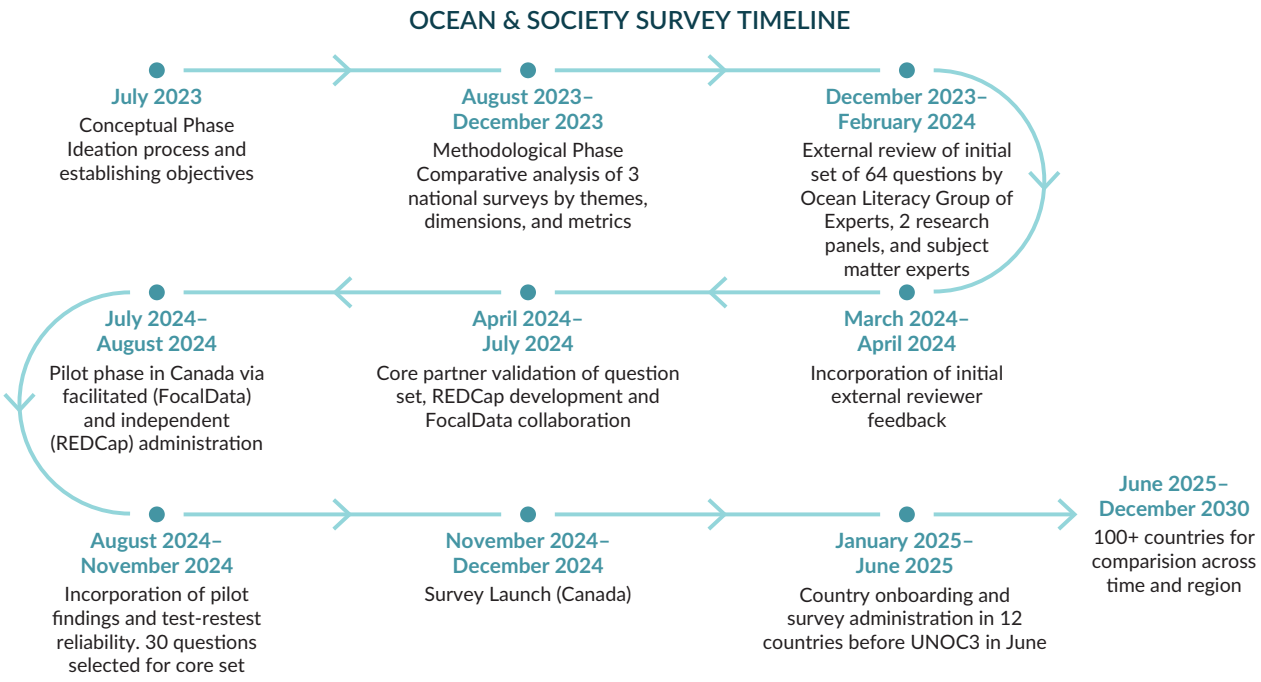

Figure 4. Ocean & Society Survey co-development timeline.

At the time of writing, 12 countries have administered the Survey prior to the UN Ocean Conference in Nice, France, in June 2025, with capacity to onboard additional countries on a rolling basis. Concurrent with these facilitated administration advances, there have been expressions of interest for independent administration to support ocean advocacy campaigns, as well as post-secondary projects for country-wide and secondary education settings.

3. Discussion

Given the diversity of ways that people connect to and depend on the ocean, the Survey proposes one means of gathering public insights on how people understand, value, and engage with it. Prioritizing the social dynamics of ocean health emphasizes that it is the lived experiences, place-based dependencies, attachments, and identities that truly shape how individuals engage with the ocean (Glithero et al., 2025). Peoples' connections to the ocean are deeply influenced by their cultural, geographic, and personal contexts, which in turn inform their attitudes, behaviours, and willingness to act. By capturing these nuances, the Survey enables enhanced data-led insights for better-aligned strategic activity across the ocean community. These insights can guide the design, facilitation, and coordination of effective engagement pathways, communication strategies, and decision-making toward measurable, solution-focused action. By mapping public ocean perceptions across different audiences over multiple Survey iterations (until 2030), we can track changes in people–ocean connections and ocean literacy. This enables the global ocean community to iteratively refine their understanding of what drives peoples'/communities' engagement in place-based solutions.

Ocean solutions depend on collective action across multiple sectors, scales, and disciplines. The Survey's focus on identifying behavioural motivations, barriers, and enablers opens new avenues for collaboration, enabling diverse stakeholders to work together in addressing shared challenges in ways that align with the

priorities of the people directly impacted by those challenges. By foregrounding the diversity of connections people have with the ocean, the Survey challenges the notion that simply providing more information will solve shared ocean health challenges. Instead, it highlights the need for dynamic, two-way engagement processes that involve people and communities in contributing to solutions and fostering a sense of shared ownership over ocean health outcomes. This cooperative approach is essential for ensuring that solutions are not only scientifically sound but also socially and culturally relevant, increasing their likelihood of success.

Central to the Survey's credibility and relevance is its foundation in a highly collaborative development process. Through an 18-month co-design effort, 20 core partners, and over 30 collaborators from across the Global North and South contributed to the conceptual, strategic, and methodological design of the Ocean & Society Survey. This transdisciplinary approach significantly enriched the instrument, embedding a diversity of perspectives and ensuring global applicability. The collaboration fostered legitimacy, promoted shared ownership, and strengthened methodological rigour by integrating expertise across ocean science, communications, education, psychology, and social science research. At the same time, the process demanded time, resources, facilitation, and coordination to navigate differing opinions and to ensure continuous engagement. Despite these nuances, the benefits far outweighed the trade-offs—yielding a robust and adaptive survey tool that reflects both local specificity and global comparability. The collaborative nature of its development sets a precedent for future public ocean perceptions research and resultant uptake grounded in equity, inclusion, and co-creation.

The Survey provides evidence-based and context-specific insights that speak directly to the values, concerns, and experiences of different groups of people, making the issue of ocean health more relatable and actionable. By capturing a range of ocean literacy themes and dimensions, the Survey offers insights into how individuals perceive their connection with the ocean and what drives or hinders this connection. The responses help illuminate pathways of engagement, from awareness to action, and highlight the importance of targeted communication, trust-building, and accessibility to support sustainability practices. Overall, the Survey facilitates a nuanced understanding of the social dynamics underpinning ocean-related behaviour change, reinforcing the need for multi-dimensional strategies that align with diverse values and capacities within and across cultures and geographies.

Additionally, as the Survey intends to collect data over time, it highlights the importance of strategies that evolve alongside the changing social landscape. Public perceptions of the ocean are not static, and the challenges facing the ocean are continually shifting due to factors such as climate change, technologies, and social and political contexts. By regularly gathering data on public ocean perceptions, the Survey offers a mechanism for monitoring these shifts and adjusting strategies accordingly. This ongoing feedback loop is crucial for maintaining the momentum of public engagement and ensuring that efforts to restore ocean health remain responsive to the needs and connections of diverse populations.

The Survey response to the Ocean Decade Challenge 10 calls for a more holistic, people-driven framework for addressing the interconnected challenges facing the ocean. The urgent need for this shift is underscored by the rapid increase in support for the Survey, growing from just one country with dedicated funding to 12 countries within 3 months. The goal is to administer the Survey in at least 100 countries by 2030. Looking ahead, the Survey requires sustained global collaboration to advance research and application. One

burgeoning effort toward this end, is the development of the Ocean & Society Engagement Lab, launching in 2025. Keeping in line with the Survey efforts in transdisciplinary collaboration, the multi-partner Ocean & Society Engagement Lab aims to translate Survey findings into actionable strategies and targeted outputs to help drive real-world impact. Central to the overarching Lab, an Insights Application Hub will democratize access to the research insights and help ocean conservation communicators, practitioners, and decision-makers develop more effective, evidence-based strategies. The Hub will disseminate insights through reports and infographics, support campaigners in translating data into communication strategies, generate talking points for stakeholders, engage journalists with societal insights for impactful media coverage, and convene the ocean community through workshops and clinics to co-develop evidence-based approaches. The project builds on extensive partnerships with organizations including the Canadian Ocean Literacy Coalition, Communication INC, and numerous global ocean conservation networks (e.g., OneOcean Flotilla), with the ultimate goal of achieving both policy wins and long-term behavioural change for improved ocean health.

4. Conclusion

By understanding what motivates people to take action—or what holds them back—we can create clear, place-based pathways that enhance society's understanding, value, and care for the ocean (i.e., increased ocean literacy). The circulation and launch of the Ocean & Society Survey in 2025 coincides with a critical halfway juncture in the Ocean Decade, offering invaluable insights on people–ocean connections to ultimately galvanize society's role and widespread public engagement in ocean health solutions.

Acknowledgments

We acknowledge and appreciate the valuable contributions of international collaborators (and collaborating institutions) whose expertise and commitment have been critical to the success of this project. Their efforts, spanning diverse disciplines and regions, have provided essential guidance, insights, reviews, and resources that have strengthened the work. Built on this foundation, continued collaboration is invited to pursue Ocean & Society Survey goals over the next five years to monitor changes in public ocean perceptions over time, toward ocean literacy as a societal outcome.

Authors contributed in the following order: Jen McRuer contributed to conceptualization, methodology, validation, resources, writing—original draft—review and editing, visualization, and project administration; Diz L. Glithero to conceptualization, methodology, validation, resources, writing, review and editing, visualization, project administration, and funding acquisition (project and Survey administration); Emma McKinley to conceptualization, methodology, validation, writing, and review and editing; Jordi F. Pagès to methodology, validation, data curation, and analysis; Géraldine Fauville to methodology, validation, writing, review and editing, and funding acquisition (Survey administration); Elisabeth S. Morris-Webb to methodology, validation, writing, review and editing, and funding acquisition (Survey administration); Natalie Hart to methodology, validation, and visualization; Craig Strang to methodology and validation; Ronaldo Christofoletti to conceptualization, methodology, and funding acquisition (Survey administration); Sophie Hulme to methodology, visualization, and funding acquisition (Survey administration); Elliot Grainger to methodology, visualization, writing, review, and editing; Bárbara Pinheiro to conceptualization and methodology; Diana L. Payne to conceptualization, methodology, and funding acquisition (Survey administration); Nicola Bridge to conceptualization, methodology, and funding acquisition (Survey administration); Vinicius Lindoso to

conceptualization, methodology, and visualization; Ivan Machado Martins to methodology and visualization; David Zandvliet to methodology and validation; Marilia Bueno Fernandes to methodology, writing, review, and editing; Janaina Bumbeer to methodology; and Rebecca Shellock to Methodology.

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Conflict of Interests

In this article, editorial decisions were undertaken by Benedict McAteer (Queen's University Belfast), Berit Charlotte Kaae (Københavns Universitet), and Brice Trouillet (Nantes Université).

Data Availability

Data is available upon request by contacting the corresponding author, or by visiting https://oceanliteracyresearch.com/ocean-and-society-survey

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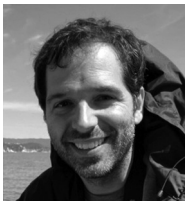

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ARTICLE

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Ocean Literacy as a Strategic Asset for Regional Marine Policy: Insights From an Implementation Case Study

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Abstract

Ocean literacy (OL) has increasingly been recognised as a key enabler of participatory marine governance, with potential synergies with maritime spatial planning (MSP). These links are particularly evident in stakeholder engagement processes, which are mandated by the European MSP Directive and supported by international institutional guidelines. OL can facilitate these processes by fostering informed participation, enhancing public awareness, and supporting educational and cultural goals aligned with Sustainable Development Goal 14 "life below water." Within the framework of the EU-funded Regions to Boost National Maritime Spatial Planning-MSP project, a methodology was developed to support the design of a Regional Ocean Literacy Strategy aimed at strengthening MSP implementation at the sub-national (NUTS-2) level. This article outlines the development of a structured toolbox to support regional OL strategies and presents the results of its empirical testing in the Sardinia region. The findings indicate that regional actors acknowledge the relevance of OL for marine management and that existing assets—such as environmental education networks and cultural initiatives—can be effectively mobilised through a strategic framework. The study demonstrates the feasibility and replicability of the approach, offering a model that can be adapted and transferred to other regional contexts across Europe.

Keywords

environmental awareness; maritime spatial planning; ocean citizenship; ocean governance; ocean literacy; policy design; regional governance

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1. Introduction

Ocean literacy (OL), initially developed in 2004 through collaborations between educators and marine scientists in the US, was conceived as a response to the marginal presence of ocean sciences in formal education (McKinley et al., 2023). This initiative produced a structured framework aimed at embedding ocean science into public education and promoting ocean-related knowledge, awareness, and responsibility. While OL's early purpose was largely pedagogical (UNESCO-IOC, 2017), the concept has since evolved to encompass broader socio-political dimensions, including public engagement, policymaking, and sustainable marine governance (S. Liu et al., 2023; McKinley et al., 2023).

In recent years, OL has gained recognition as an enabler of transformative change in ocean policy. S. Liu et al. (2023) argue that OL now plays a vital role in shaping inclusive governance and policy design. In this context, this article explores the application of OL within a specific ocean management framework: maritime spatial planning (MSP). MSP is a key policy instrument aimed at promoting the sustainable use of marine space through coordinated spatial governance (Directive 2014/89/EU, 2014). While the MSP Directive (Directive 2014/89/EU, 2014) does not explicitly reference OL, its emphasis on participatory, knowledge-based processes and coherent governance aligns closely with OL principles, particularly the sixth OL principle: "The ocean and humans are inextricably interconnected" (Halversen et al., 2021).

The connection between OL and MSP has been recognised by multiple European initiatives. For instance, the Sea Change project (French et al., 2015) analysed European marine policies and identified implicit alignment between OL and the objectives of the MSP Directive. Similarly, the 2024 Venice Declaration on Ocean Literacy and Ocean Governance called for OL to be integrated into policymaking and planning, highlighting the importance of involving stakeholders and the general public in the design of marine and coastal policies (Casati et al., 2024). These developments have elevated OL from a communication or education tool to a strategic mechanism for public participation and policy coherence.

Despite the growing interest in OL as a policy asset, most OL initiatives remain disconnected from decision-making processes. This disconnect is particularly relevant for MSP, which depends on inclusive stakeholder engagement to ensure legitimacy and effectiveness (Pomeroy & Douvere, 2008; Shellock et al., 2024). OL can enhance this process by equipping citizens and stakeholders with the knowledge and capacities needed to contribute meaningfully to marine governance (French et al., 2015; Kelly et al., 2021). Moreover, OL has been identified as a socio-cultural enabler of MSP, capable of fostering shared understanding and facilitating co-designed planning processes (McKinley et al., 2019, 2023).

An interesting international example is provided by *Land, Water, Ocean, Us: A Canadian Ocean Literacy Strategy* (Canadian Ocean Literacy Coalition, 2021), a national initiative developed outside the EU framework. While not aligned with EU Directives, the Canadian strategy offers a valuable source of inspiration. It adopts a broad, culturally grounded understanding of OL, extending beyond ocean sciences to embrace inland waters, Indigenous knowledge systems, and civic relationships with the ocean continuum. Such inclusive perspectives highlight the potential for OL to support cross-sectoral engagement and foster the social, cultural, and ecological dimensions of marine governance—an approach that resonates with ongoing European efforts to expand the scope of OL within participatory planning frameworks.

Recent literature underscores the role of OL in supporting participatory governance and integrated ocean management. For instance, Jacobs et al. (2015), T. K. Liu et al. (2023), and McRuer et al. (2025) demonstrate that OL can improve stakeholder engagement and foster science–policy–society integration. In this sense, OL acts as a bridge between people and policy, promoting inclusive dialogue and collective stewardship of marine resources. As McKinley (2024) argues, successful ocean governance depends fundamentally on understanding and improving human–ocean relationships.

Nonetheless, institutional frameworks for MSP vary widely across EU member states, particularly in how they structure stakeholder engagement and integrate sub-national actors (Casimiro & Guerreiro, 2019; Friess & Grémaud-Colombier, 2021). While the directive calls for coherence and cooperation, regional implementation remains a critical challenge (Zaucha et al., 2025). The need for participatory, multi-level governance is particularly acute when considering the inclusion of cultural knowledge, social values, and local expertise—dimensions that OL can help to surface and mobilise (Wedding et al., 2024). These are also aligned with the recent emphasis in the UN Ocean Decade on co-production of knowledge and inclusive marine science (Glithero et al., 2024).

This study builds on the premise that in the EU, regional and local institutions—particularly at the sub-national (NUTS-2) level—are key actors in the implementation of MSP and have untapped potential to support MSP goals through structured OL efforts. Specifically, it addresses the question:

> Can OL become a functional tool to support the implementation of marine policies, particularly MSP, at the regional level?

The hypothesis tested is that it is possible to compile a regionally tailored OL strategy, supported by an operational and replicable toolbox (Regional Ocean Literacy Strategy for MSP [ROLS-MSP]), which can assist regions in both designing and implementing OL-informed marine governance frameworks. Rather than testing a fully pre-existing strategy, this study evaluates the development, co-design, and testing of a novel toolbox intended to guide regional authorities in integrating OL into their MSP activities. The approach combines insights from policy design theory (Junginger, 2014, as cited in Bason, 2014), system dynamics (Brennan et al., 2019), and multi-level governance to support a process of iterative, context-sensitive strategy development. It responds directly to calls for more systemic, locally relevant, and empirically grounded approaches to embedding OL in governance processes (Ferreira et al., 2021; Paredes-Coral et al., 2021). By investigating the application of the toolbox in different regional contexts—particularly through its testing in Sardinia—this study contributes to the emerging body of literature on OL as a governance mechanism. It offers evidence on how OL can function beyond education, as a lever for participatory marine planning, policy coherence, and regional capacity building. In doing so, it explores the potential for a more integrated science–policy–society interface in ocean governance.

2. Methods

This study was conducted within the framework of the project Regions to Boost National Maritime Spatial Planning (REGINA-MSP), which aims to enhance the role of regional (NUTS-2) authorities in the development and implementation of MSP. The methodological approach adopted here follows a structured and iterative design process, drawing on the principles of policy design (Junginger, 2014, as cited in Bason, 2014) and rooted in transdisciplinary inquiry.

The main objective was to design and test a replicable Regional Ocean Literacy Strategy for MSP (ROLS-MSP) toolbox to guide regional authorities in developing OL strategies aligned with MSP implementation. The methodology involved three main phases: (a) development of the ROLS-MSP toolbox, (b) participatory review and refinement through expert workshops, and (c) pilot testing in the Sardinia region. The full process is summarised in Figure 1.

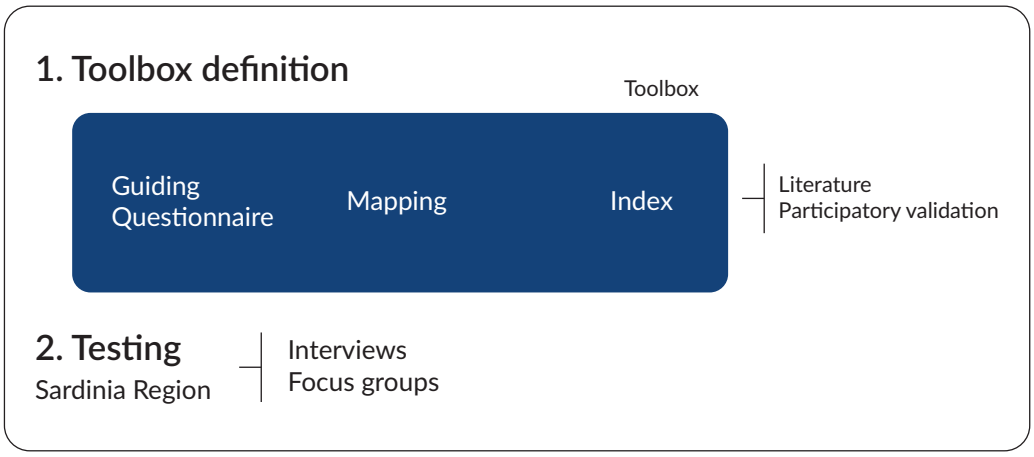

Figure 1. Methods and their sequential employments to test the toolbox.

2.1. Toolbox Development

The toolbox was developed through an integrative process involving a literature review, expert consultation, and design synthesis. The review phase examined core OL concepts and frameworks, including the UNESCO-IOC (2017) OL toolkit, key scholarly contributions (e.g., French et al., 2015; Kelly et al., 2021; McKinley et al., 2019), and relevant policy documents such as the MSP Directive (2014/89/EU, 2014) and the European Commission's Communicating MSP guidelines (Executive Agency for Small and Medium-sized Enterprises , 2020). The literature also informed the proposed conceptual alignment between OL and MSP, positioning OL not simply as an educational agenda but as a governance asset capable of enhancing stakeholder engagement and policy coherence. Specific attention was given to the multidimensionality of OL, including scientific, educational, cultural, and participatory components (Halversen et al., 2021; UNESCO-IOC, 2017). Inspired by policy design theory, the design process emphasised iterative testing, stakeholder input, and contextual sensitivity (Junginger, 2014, as cited in Bason, 2014). From this foundation, a strategic toolbox was constructed comprising three main tools: a guiding questionnaire (see Section 2.3.1), to assess the region's OL capacity and identify entry points for integration into MSP; a mapping tool (see Section 2.3.2), to spatially visualise OL-related assets and detect regional imbalances; a strategy index (see Section 2.3.3), to guide regional authorities in structuring their OL strategy across multiple thematic areas. The tools were designed to be applicable across diverse regional contexts and to facilitate the co-design of OL strategies that reflect local assets, institutional capacities, and stakeholder networks.

2.2. Toolbox Objectives and Thematic Threads

The toolbox was designed with a specific user group in mind: regional and local institutions responsible for MSP-related implementation. Its overarching purpose is not to disseminate OL in isolation but to use OL strategically to strengthen MSP governance and societal engagement.

To ensure the toolbox responded to practical governance needs, seven specific objectives were identified based on a synthesis of the MSP Directive (EU, 2014), the UNESCO-IOC toolkit (2017), and the UN Sustainable Development Goals (UN, 2015). To operationalise these objectives, the toolbox is structured around four thematic "threads of opportunity": education, research, culture, and regulation. These threads were derived from the seven perspectives of OL described in the UNESCO-IOC (2017) framework and serve to guide strategy formulation based on existing assets and institutional priorities.

2.3. Toolbox Components

2.3.1. Guiding Questionnaire

The questionnaire was designed to help regional officers assess the status of OL in their territory and identify strategic priorities. It employs a structured YES/NO format with follow-up filters (Brancato et al., 2006) and includes 11 questions, each linked to one of the four thematic threads. Each response generates tailored recommendations, and some answers trigger cascaded sub-questions to probe further into existing practices (Taherdoost, 2022). The questionnaire is informed by existing tools in public policy assessment and OL monitoring (Boparai et al., 2018) and was constructed to ensure usability by non-experts. The questionnaire serves as both a diagnostic and planning tool.

2.3.2. Mapping Tool

The mapping component supports the spatial visualisation of OL initiatives and assets across regional territories. It allows authorities to identify geographic gaps, assess coverage, and support spatially balanced MSP-related communication and education. This tool is grounded in landscape and seascape character assessment methodologies (Natural England, 2012; Tudor, 2014) and adapted from spatial approaches used in French and Spanish MSP practices (Barianaki et al., 2024). Short questionnaires (see Supplementary Files) were used to collect geolocated data on OL initiatives, including providers, institutional types, funding, target audiences, and pedagogical methods.

2.3.3. Strategy Index

The strategy index (see Supplementary Files) provides a structured template for drafting a comprehensive OL strategy aligned with MSP goals. It includes:

- An introduction and vision section;
- A state-of-the-art review (social, environmental, cultural, and policy context);
- Thematic strategies across education, research, culture, and communication;
- Monitoring and evaluation criteria;
- Guidelines for regional cooperation and best practice sharing.

The index also provides a logic model for linking OL activities with MSP implementation goals, including stakeholder engagement during key planning phases and plan review periods.

2.4. Participatory Refinement and Expert Validation

To enhance the scientific robustness, contextual relevance, and user applicability of the ROLS-MSP toolbox, a participatory refinement process was integrated into the methodology. This process drew on the principles of policy co-design and transdisciplinary inquiry (Junginger, 2014, as cited in Bason, 2014; Ten Holter, 2022), allowing for iterative adjustments to the toolbox prior to its empirical testing.

2.4.1. International Interdisciplinary Workshop

The workshop was held in Sardinia in May 2023 and brought together 34 participants, including representatives from UNESCO-IOC, regional administrations, universities, NGOs, marine parks, science communicators, and environmental educators. The session served to validate the conceptual basis and structure of the toolbox, as well as to assess the coherence of its components with real-world OL practices and MSP processes. During the workshop, regional partners presented exemplary OL initiatives from their territories. These were documented using a standardised factsheet, which included details such as institutional context, target audience, funding model, thematic content, and degree of relevance to MSP. Following the presentations, a structured review of the draft toolbox was conducted through facilitated discussions. Feedback focused on improving the cultural adaptability, operational clarity, and communication features of the tools.

The workshop outcomes directly informed revisions to the guiding questionnaire (e.g., simplifying language and adding examples), the thematic threads (e.g., integrating cultural heritage), and the strategy index (e.g., including evaluation mechanisms and cross-sectoral partnerships).

2.5. Empirical Testing: The Sardinia Case Study

The ROLS-MSP toolbox was subsequently tested in a real-world setting to evaluate its usability and functionality in supporting the development of an OL strategy aligned with MSP. Sardinia, a NUTS-2 level Italian region, was selected as the pilot site due to its advanced involvement in MSP processes (Ramieri et al., 2024), well-established environmental education infrastructure (such as the Programmi Regionali di Informazion, Formazione ed Educazione all'Ambiente e alla Sostenibilità [INFEAS]), and active participation in the REGINA-MSP project.

2.5.1. Case Selection and Contextual Fit

Sardinia was identified as an appropriate test case based on a confluence of favourable contextual conditions. The region has consistently demonstrated institutional engagement with national marine spatial planning efforts and has developed internal capacities through existing governance structures, including several departments with relevant mandates in environmental sustainability, education, transport, and communication. Moreover, the strong collaboration between regional institutions and research centres—such as the National Research Council's Institute for the Study of Anthropic Impacts and Sustainability in the Marine Environment (CNR-IAS) and the IMC Foundation—offers a noteworthy example of an effective science–policy interface. This collaboration, which was also evident in the REGINA-MSP project, supports both research and dissemination activities in the marine domain. In addition, Sardinia benefits from an

extensive environmental education network—namely the INFEAS system—which includes the Centri di Educazione alla Sostenibilità (CEAS). This network represents an established channel through which marine and sustainability-related knowledge is already disseminated at the regional and local levels. The presence of this infrastructure offered a unique opportunity to explore how OL principles might be systematically incorporated into MSP-related strategies and communication. The inclusion of interdepartmental coordination mechanisms and stakeholder engagement platforms further enhanced the suitability of Sardinia for this pilot test. These characteristics made it possible to apply the toolbox across multiple governance levels and thematic domains, ensuring a comprehensive assessment of its practical functionality and replicability.

2.5.2. Data Collection Methods

The testing phase employed qualitative methods, namely structured interviews and focus groups, using the ROLS-MSP toolbox components both as research instruments and as decision-making frameworks. The research team coordinated closely with Sardinian institutional stakeholders and regional actors to implement the following two data collection activities. First, structured interviews with representatives from six regional departments: environment and sustainability, transport infrastructure, maritime and air transport, tourism, communication, and institutional planning. Each interview was guided by the toolbox questionnaire and supplemented by questions tailored to the department's thematic domain. Second, two focus groups were conducted, each composed of approximately 20 participants from the fisheries and aquaculture sectors. These sessions were designed to test the accessibility and relevance of the toolbox's thematic threads (education, regulation, culture, and research) from the perspective of end users and stakeholders directly affected by marine spatial policies. Mapping exercises were conducted to spatially identify and categorise existing OL-related assets in the region. These included marine education centres, NGOs, museums, academic institutions, and communication platforms. Data collection followed a predefined questionnaire and was visualised through an open-source geospatial platform (Google Maps), accessible to the regional administration. Strategy drafting, in which the research team synthesised the data collected into a coherent ROLS-MSP, based on the structural guidance provided by the strategy index. All interviews and focus groups were recorded and transcribed with the participants' consent, and anonymised notes were used to ensure data confidentiality. Supplementary materials, including questionnaires and strategy templates, were provided to all participants to support transparency and replicability.

2.5.3. Analytical Approach

The qualitative data obtained during the Sardinia testing phase were subjected to thematic analysis, with attention to three main dimensions: institutional readiness to support OL strategies, stakeholder perceptions regarding OL's role in supporting MSP objectives, and practical barriers and opportunities for cross-departmental coordination and policy integration. The draft strategy that emerged from this process constitutes the primary output of the empirical phase. As such, it serves not only as a demonstration of the toolbox's operational functionality but also as a basis for assessing its replicability in other regional contexts. The findings and reflections arising from this test case are presented in Section 3.

3. Results

The findings presented in this section derive from the participatory validation of the ROLS-MSP toolbox and its empirical testing in the Sardinia region. These results are organised in two parts: the international workshop and the Sardinian case study. The section reports evidence of the toolbox's perceived utility, adaptability, and limitations in real-world contexts, and the outcomes of its application as a strategy-building instrument.

3.1. Results From Participatory Validation: International Workshop

The international interdisciplinary workshop conducted in Sardinia provided both content and structural feedback to refine the toolbox. Representatives from the eight REGINA-MSP regions, UNESCO-IOC, research institutes, NGOs, and educational institutions contributed examples of OL initiatives currently implemented in their respective territories. The presentations showcased a wide diversity of practices, ranging from formal educational programmes (e.g., Blue Schools in Italy and the Calypso initiative in France) to museum-based heritage outreach (e.g., ARQVA Underwater Museum in Spain), artistic engagement (e.g., the Irish Fair Seas campaign), and gender-inclusive science communication (e.g., Oceanicas by the Spanish Institute of Oceanography). Several of these initiatives exhibited implicit or explicit links with MSP-related goals, such as fostering marine stewardship, promoting marine spatial awareness, and enabling participatory management. Participants expressed strong interest in the toolbox as a means of structuring and scaling such activities. They highlighted the importance of broadening the OL framework beyond traditional environmental education, including underexplored domains such as cultural heritage, culinary traditions, and creative industries. Moreover, the workshop revealed a general demand for regionally adaptable tools that could facilitate cross-sectoral collaboration and policy integration. These inputs were instrumental in adjusting the guiding questionnaire for clarity and inclusivity, refining the thematic threads to accommodate cultural perspectives, and expanding the strategy index to include new forms of regional engagement. The workshop also confirmed the feasibility of using the toolbox across different national systems and administrative structures.

3.2. Sardinia Case Study: Application and Outcomes

The Sardinian pilot served as the empirical application of the toolbox, culminating in the development of a draft ROLS-MSP. The process confirmed the toolbox's practical utility in guiding the formulation of a regional strategy rooted in existing assets and institutional structures. Structured interviews were conducted with six departments of the Sardinian regional administration. These included the Servizio Sostenibilità Ambientale, Valutazione Strategica e Sistemi Informativi, the Servizio Infrastrutture di Trasporto e della Sicurezza Stradale, the Servizio per il Trasporto Marittimo e Aereo e Continuità Territoriale, the Assessorato del Turismo, Artigianato e Commercio, and the Servizio Comunicazione Istituzionale. The interviews, structured around the guiding questionnaire, allowed for the identification of OL-relevant assets and institutional responsibilities, as well as for the assessment of departmental awareness of and engagement with MSP objectives. In addition, two focus groups were organised in October 2023 in Asinara and the Gulf of Olbia, targeting the fisheries and aquaculture sectors, respectively. Each session included approximately 20 participants. These focus groups used selected sections of the toolbox as facilitation instruments and revealed the relevance of OL themes—such as sustainability, regulatory literacy, and cultural heritage—to stakeholder experiences. Participants emphasised the importance of using simple language, locally relevant

examples, and practical illustrations of OL-MSP connections. The mapping exercise enabled the spatial identification of OL practices and infrastructures across the Sardinian territory. Using an open-access format on Google Maps, the regional team produced an interactive visual representation of key assets. These included the CEAS, marine research institutions, museums, parks, and non-formal education providers. This mapping activity helped reveal spatial disparities and underutilised areas and was considered a valuable tool for inclusive regional planning (Figure 2).

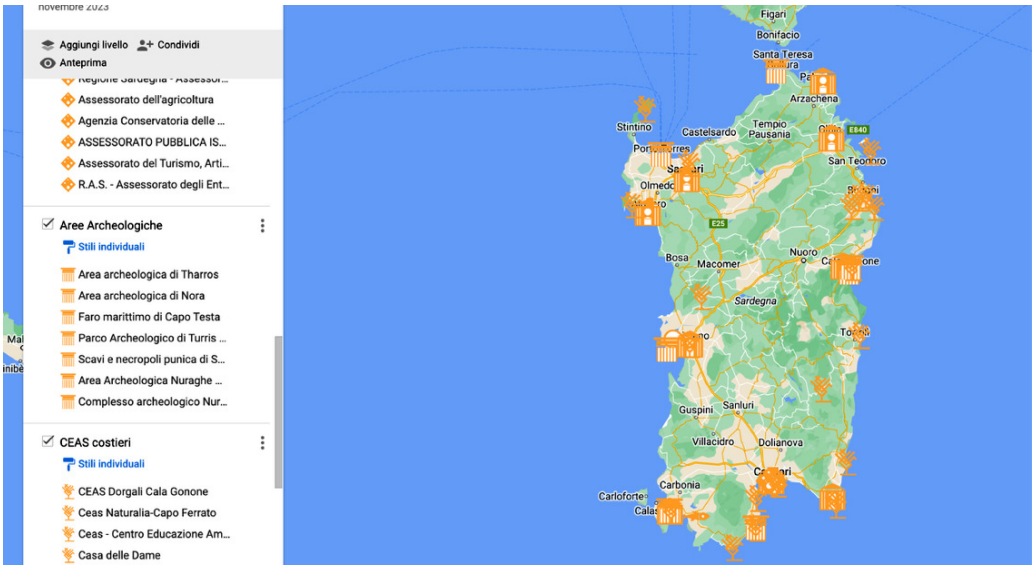

Figure 2. Sardinia ROLS-MSP interactive map. Note: Figure based on Soffietti et al. (2023).

The strategy's structure was developed using the strategy index component of the toolbox. This process enabled the formulation of a document that integrated the four thematic threads (education, culture, research, and regulation) with existing institutional capacities and potential cross-sectoral synergies. In particular, the INFEAS network and the CEAS centres were identified as foundational infrastructures for OL activities. Although Sardinia does not currently possess the administrative mandate or dedicated resources to formally adopt the strategy, the exercise demonstrated that OL assets could be systematically organised to support MSP implementation. Interviews with regional officers also revealed recurring governance challenges, including departmental fragmentation, coordination difficulties, and funding constraints—factors that could undermine long-term implementation without targeted institutional support.

Moreover, the test process underscored the strategic role of the INFEAS educational network, which appeared as the most consolidated regional framework relevant to OL. Its potential to act as a connective hub for other departments and initiatives was highlighted. The idea of establishing a unifying structure, such as a regional "District of the Sea" (as envisioned in the Italian MSP draft plans), was proposed as a mechanism for cross-sectoral integration and participatory engagement (see Figure 3).

Feedback from stakeholders also stressed the need to incorporate regional languages or dialects into public communication to improve community outreach and foster cultural proximity. Additionally, participants suggested that providing sector-specific examples of OL applications—such as tourism, fisheries, or education—could facilitate engagement by illustrating the direct benefits of the strategy. In summary, the Sardinia case validated the operational usability of the toolbox while also surfacing context-specific barriers

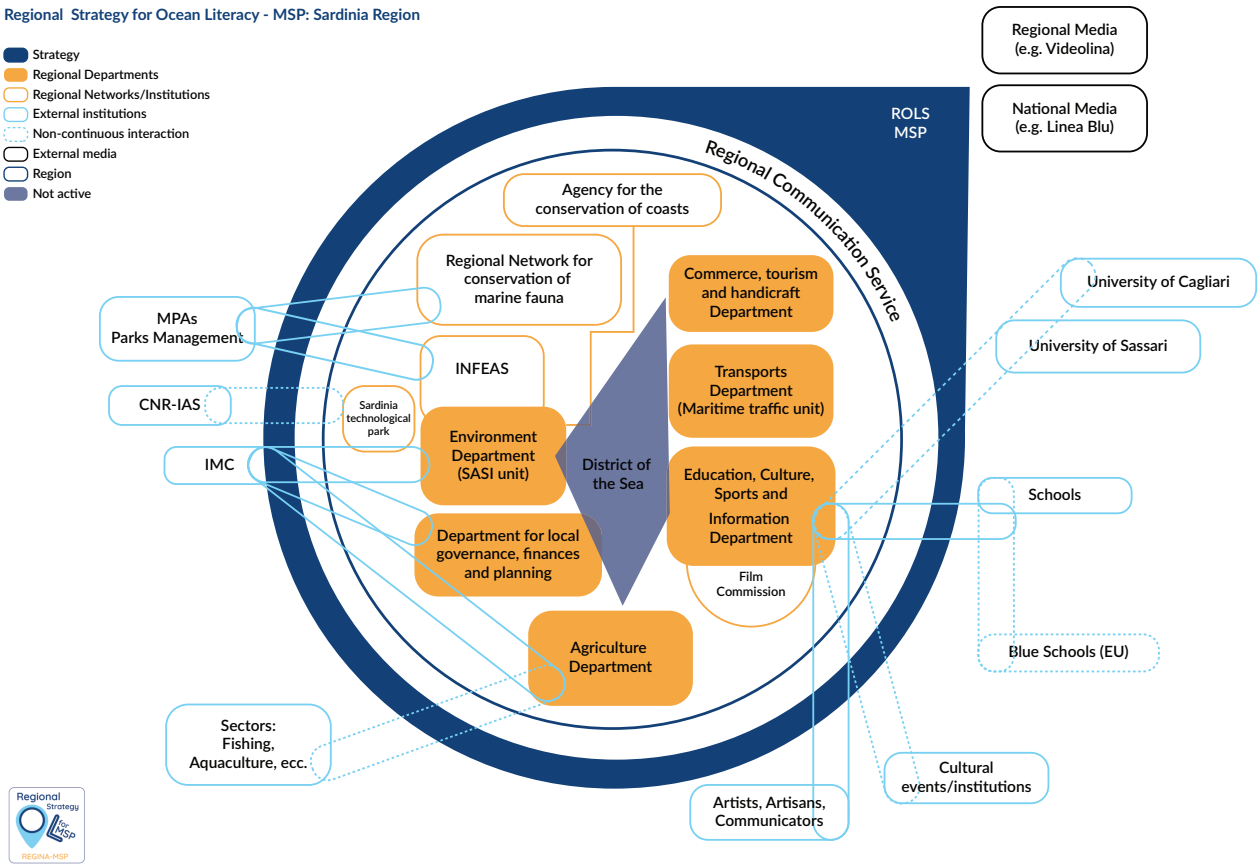

Figure 3. ROLS: Sardinia ROLS-MSP structure. Notes: This figure is based on Soffietti et al. (2023). CNR-IAS stands for Centro Nazionale delle Ricerche—Istituto per lo Studio Degli Impatti Antropici e Sostenibilità in Ambiente Marino (in English, National Research Council—Institute for the Study of Anthropic Impacts and Sustainability in the Marine Environment); IMC stands for Fondazione IMC—Centro Marino Internazionale ONLUS (in English, IMC Foundation—International Marine Centre NPO).

and recommendations. The resulting draft strategy provides a tangible model for regional OL integration within MSP, structured according to an empirically grounded and participatory methodology.

4. Discussion

The findings from the Sardinia test case, supported by the prior expert workshop, confirm that OL can be operationalised as a functional support tool for MSP at the regional level. The successful application of the ROLS-MSP toolbox demonstrates that, when OL is framed not solely as an educational resource but as a strategic governance instrument, it can enable regions to organise existing knowledge assets, strengthen public engagement, and contribute meaningfully to marine policy implementation. Nevertheless, there are structural similarities that can be observed across Italian regions, many of which also apply to other European contexts. One common challenge is the complexity of aligning the objectives and activities of various departments, which span areas such as marine protection, education, maritime economics, and spatial planning. While each administrative unit holds the potential to contribute to OL and MSP processes, coordination between them is often limited. Fragmentation, overlapping mandates, and varied operational cultures present persistent barriers to integration. In addition to these institutional challenges, financial

coordination across departments represents another hurdle, particularly in regions that rely on project-based or time-limited funding streams. As most regional administrations function through multiple, semi-autonomous departments, developing mechanisms to support interdepartmental collaboration is a necessary condition for strategy implementation.

The Sardinian case also reveals the importance of having an existing infrastructure—such as the INFEAS environmental education network—which can act as a foundation for OL initiatives. Leveraging such structures may accelerate implementation and reduce duplication of effort. However, even in regions with well-established educational or communication assets, the absence of formal integration into planning and governance processes limits OL's potential impact. As noted by S. Liu et al. (2023), without institutional recognition and strategic positioning, OL remains peripheral to decision-making. A key contribution of the toolbox is its ability to provide a replicable yet adaptable methodology that regional authorities can use to navigate this complexity. The structured approach of the guiding questionnaire and the strategy index enables departments to assess current efforts, identify gaps, and define a shared vision for OL, while the mapping tool supports equity and transparency in the spatial distribution of initiatives. This aligns with what Ferreira et al. (2021) have argued: that OL must be embedded in broader strategies, supported by well-defined objectives, and linked to operational tools. The empirical test also confirms the hypothesis that it is possible to produce a regionally tailored OL strategy through a structured, participatory process. Importantly, the strategy produced was not theoretical but grounded in the region's assets, capacities, and administrative architecture. The test further supports the idea that such a strategy can be both context-specific and potentially replicable in other settings, particularly if supported by enabling frameworks, such as interdepartmental working groups or dedicated regional coordination units. This finding resonates with recent developments in policy design theory, particularly in relation to iterative, multi-actor, and future-oriented processes (Bason, 2014). In this sense, the toolbox serves not only as a diagnostic device but also as a design instrument—one that helps institutions envision and co-produce pathways toward more inclusive and resilient ocean governance.

Furthermore, the Sardinia case underlines the relevance of OL at the science–policy–society interface. As highlighted by Paredes-Coral et al. (2021) and Shellock et al. (2024), OL should not be limited to increasing awareness but should facilitate knowledge co-production and informed participation. In this respect, the strategy's emphasis on cross-sectoral collaboration, use of local languages, and engagement with cultural heritage aligns well with recent calls to integrate social, cultural, and ecological knowledge into MSP (Glithero et al., 2024; Wedding et al., 2024). The process also suggests that OL can serve as an entry point for broader participatory governance in coastal and marine affairs. While MSP typically includes formal stakeholder consultation opportunities, these are often too infrequent or too technical to foster meaningful engagement (Twomey & O'Mahony, 2019). Embedding OL within MSP provides a means to prepare, educate, and empower stakeholders before and beyond these formal processes—thereby enhancing both the legitimacy and quality of marine planning. However, the test also highlights limitations. The successful drafting of a strategy does not automatically guarantee its institutional adoption. Even with interest from regional actors, implementation will depend on sustained political will, budgetary allocations, and possibly legal mandates. Moreover, as acknowledged by the research team, testing a toolbox is not equivalent to testing the long-term socio-cultural or economic impacts of the strategy it generates. While the Sardinia case indicates strong potential, further applications in diverse governance contexts are needed to fully assess the tool's versatility and resilience.

5. Conclusions

This study sets out to examine whether OL could be operationalised as a functional tool to support regional MSP processes in the EU context. In response to this research question, the study tested the hypothesis that a replicable, regionally adaptable OL strategy could be developed through a structured methodological toolbox (ROLS-MSP). The results of the Sardinia pilot and the preceding expert validation process confirm this hypothesis, demonstrating that OL can be leveraged not only as a communication or educational asset but also as an integrative framework for participatory ocean governance.

Building on prior literature that positions OL at the science–policy–society interface (Kelly et al., 2021; Paredes-Coral et al., 2021), this study reinforces the importance of shifting OL from the periphery of marine governance into the core of strategic policy design. Ferreira et al. (2021) emphasise the need for OL to be embedded within broader strategies defined by clear goals and objectives. In this context, the REGINA-MSP project contributed a practical approach: a structured toolbox capable of supporting regional authorities in formulating an OL strategy aligned with MSP objectives and the Sustainable Development Goals.

The empirical test in Sardinia confirmed the operational feasibility of the toolbox, despite the limitation of regional resources. Through a combination of structured interviews, focus groups, and mapping exercises, regional actors were able to identify existing assets, articulate shared objectives, and draft a comprehensive OL strategy. While the Sardinia Region does not currently possess the institutional mechanisms required to formally adopt the strategy, the process revealed both the interest and the latent capacity for implementation. The findings suggest that, even in the absence of dedicated OL policy frameworks, structured tools can facilitate interdepartmental collaboration, increase stakeholder awareness, and improve preparedness for future participatory processes. The study also highlights the importance of working with existing regional resources and infrastructures, particularly those already engaged in environmental education, sustainability, and cultural dissemination. This approach is supported by recent literature advocating for inclusive, locally anchored knowledge co-production in MSP (Glithero et al., 2024; Wedding et al., 2024). Moreover, as McKinley (2024) argues, balancing the tensions between growth, equity, and sustainability also requires acknowledging and leveraging existing strengths within governance infrastructures.

Nonetheless, the research recognises important limitations. Testing the toolbox does not equate to testing the long-term impacts of a fully implemented strategy. Future research will be needed to evaluate the effectiveness of such strategies in generating behavioural, institutional, or ecological outcomes, within full policy cycles. Furthermore, the study was limited to a single regional test. Expanding the application of the ROLS-MSP toolbox to additional regions across different governance settings—both within and beyond the Mediterranean basin—would provide a more robust basis for assessing its transferability and long-term utility. In this regard, it could also be valuable to explore comparisons with extra-EU experiences, such as *Land, Water, Ocean, Us: A Canadian Ocean Literacy Strategy* (Canadian Ocean Literacy Coalition, 2021), which offers an inspiring model of culturally grounded OL integration, albeit developed outside the EU's policy framework. Despite its limitations, this study provides both a methodological and conceptual contribution to the evolving field of OL and its integration into marine spatial governance. It introduces a replicable model for enhancing the institutional role of OL within ecosystem-based, participatory planning processes such as MSP. The Sardinian case study demonstrates that OL can be strategically mapped, coordinated, and mobilised to support marine policy development at the regional level. More broadly, the findings contribute

to advancing understanding of how cultural and educational assets can be meaningfully embedded in policy design and implementation, thereby improving the overall effectiveness and inclusivity of ocean governance.

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Conflict of Interests

The authors declare no conflict of interests.

LLMs Disclosure

Artificial Intelligence was only used to improve English style and correctness.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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ARTICLE

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PPGIS-Mapping of Coastal-Marine Recreation: Participatory Tool for Increasing Ocean Literacy in Planning and Management?

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Abstract

Increased ocean literacy is needed not only in relation to formal education, the public, and industry, but also in policy, planning, and management of coastal and marine areas. While environmental data is often available, there is a need to also understand the human recreational uses, experiences, benefits, and problems linked to the ocean and integrating this into planning. This article discusses public participation geographical information system (PPGIS)-mapping as a potential participatory method in ocean literacy, focusing on knowledge exchange in the public-planning interface based on a Norwegian case study. The Oslo Fjord in Norway is impacted by environmental degradation, increasing urbanization, accessibility problems, and user conflicts, and the Norwegian Ministry of Environment is preparing a comprehensive plan for the fjord involving 26 municipalities with 1.7 million inhabitants. A lack of recreation data was identified, and a PPGIS survey was conducted. The results (12,445 responses) provide extensive quantitative and qualitative knowledge of recreational uses combined with spatial mapping. Participation in fjord-oriented recreation activities was high (71%) and provided health benefits, but 27% perceived problems related to accessibility, environment, or other users. In addition, mapping and open-ended questions provided detailed information on specific problems and user-generated suggestions on solutions. This study in coastal Norway helps to demonstrate how a PPGIS-mapping approach can be used as a tool for coastal and marine management and planning and how, more broadly, a public participation mapping approach can be used to increase ocean literacy among community members, planners, managers, and policy makers. We discuss how experience-based knowledge and mapping by recreationists may link to the 10 ocean literacy dimensions. Adding geospatial mapping data to the wider concept and field of ocean literacy research may provide new insights and understanding of ocean literacy dimensions and how social science may contribute to more sustainable ocean policy, planning, and management.

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Keywords
coastal and marine recreation; coastal management; fjord; marine management; Norway; ocean literacy; PPGIS-mapping; recreation management; spatial planning

1. Introduction

The ocean is increasingly impacted by anthropogenic stressors, causing severe degradation of the marine ecosystems and reduction of the goods and services they provide for human well-being and prosperity (Shellock et al., 2024). Key impacts on the ocean often originate from land use, such as eutrophication, population growth, increasing urbanization, rising individual consumption, and climate change (Nash et al., 2017), and marine environmental decline is predicted to continue (Halpern et al., 2015, 2019; Jouffray et al., 2020). This will lead to a critical need for ocean management (Hobday & Cvitanovic, 2017; Salinger et al., 2016). Solutions to the ocean problems are connected to social values and societal environmental behavior (Gifford, 2014; Wynveen et al., 2015) and to social and marine governance (United Nations Environment Programme, 2021; Veríssimo, 2013). To ensure successful governance outcomes, increased ocean literacy (OL) is needed.

OL was initially defined as an "understanding of the Ocean's influence on humans and of our influence on the Ocean" (Cava, 2005, p. 5), along with seven essential principles to support the definition of ocean literacy, but is now viewed more as a process and an outcome resulting in a society that understands, values, and cares for the ocean (Glithero et al., 2024). Brennan et al. (2019) identify six dimensions of OL: knowledge, awareness, attitude, behavior, communication, and activism. McKinley et al. (2023), meanwhile, suggest four additional dimensions: emOceans (emotional connections to the sea), access and experience, adaptive capacity, and trust and transparency. Originating in formal education, the concept and approach of OL is radically evolving into a broader tool and approach for society, aimed at stimulating actions towards ocean sustainability (IOC-UNESCO, 2021). A review of the literature on OL and spatial planning reveals multiple debates and perspectives, which are outlined in Sections 1.1–1.8.

1.1. Policy Dimensions

The principles and fundamental concepts of OL are becoming central components of international frameworks and policy goals supporting ocean sustainability policy and societal behavior change (McKinley & Burdon, 2020). They are embedded in various European regulations, e.g., the Marine Framework Strategy Directive, Blue Growth Strategy, Marine Spatial Planning Directive, and the Common Fisheries Policy (Costa & Caldeira, 2018; Fernández Otero et al., 2019; French et al., 2015). In addition, OL is also a key pillar of the UN Decade of Ocean Science for Sustainable Development (Claudet et al., 2020; Ryabinin et al., 2019). The Framework for Action by the IOC-UNESCO (2020) has also recognized OL as a transformative mechanism for understanding and reshaping society-ocean relationships. Also, the Barcelona Statement (UNESCO, 2024) resulting from the UN Ocean Decade Conference in Barcelona in April 2024, identified OL as a key strategic mechanism for ensuring the success of the Ocean Decade and the UN highlighted the need to continue to expand efforts in OL to address all sectors of society including policy makers, resource managers, and industry (UNESCO, 2024). This makes OL highly relevant for decision-makers working on international Ocean policy initiatives (Claudet et al., 2020; Ryabinin et al., 2019), as well as for national, regional, and local policy directives and sustainable

use of marine areas, e.g., marine protected areas, marine spatial planning, marine conservation, and climate change (Kelly et al., 2022).

1.2. Uneven Knowledge Collection

The number of publications on OL is increasing, including different OL literature reviews (Cavas et al., 2023; Costa & Caldeira, 2018; Paredes-Coral et al., 2021; Salazar-Sepúlveda et al., 2023; Shellock et al., 2024). Shellock et al. (2024) find a geographical bias with a concentration of OL studies in the US, Canada, UK, Ireland, and Portugal, and only one from Norway. Surveys are the predominant data collection method with students/teachers as the primary target populations, and out of the 10 OL dimensions, knowledge, access, and experience were the most studied, while activism, trust, transparency, and emOceans have received limited focus (Shellock et al., 2024).

1.3. Diverse Knowledge Systems

It is important to adopt a governance approach that recognizes the multidisciplinary and cross-sectoral nature of OL and effective ocean and coastal management, which requires a holistic understanding of the social, cultural, and economic dimensions of human–ocean interactions (Shellock et al., 2024). By bringing together diverse perspectives and knowledge systems, OL can serve as a platform for fostering inclusive and participatory governance processes, ultimately contributing to more sustainable and equitable management of marine resources and ecosystems. In this study, we add experience-based knowledge by recreational users to the existing natural science data.

1.4. Collaborative Approaches

OL is a key tool to engage society and needs to be more efficiently and widely promoted to turn into actions (Claudet et al., 2020). Increasing OL amongst decision-makers can facilitate more useful discussions among researchers, practitioners, and decision-makers and inform the development and implementation of OL initiatives and strategies (Shellock et al., 2024). This indicates a need for greater collaboration among researchers, policymakers, and stakeholders to develop practical guidance on integrating OL into marine policy and management frameworks. This collaborative approach can help bridge the gap between scientific knowledge and governance, facilitating the translation of OL concepts into actionable strategies for sustainable ocean and coastal management. Furthermore, there is a need for a more inclusive and culturally sensitive approach to OL with collaborative efforts involving diverse stakeholders, including Indigenous communities and underrepresented groups. This can enhance the acceptance and effective implementation of OL initiatives, fostering greater participation and ownership among coastal communities in ocean and coastal management processes (Shellock et al., 2024).

1.5. Community Involvement and Integration of Public Perceptions

Community involvement is a key factor, but while organized stakeholder groups are included in formal policy consultation, the opinion of individual citizens rarely enters the process of policy formation (Potts et al., 2016). It is important to include the collective choices made by individuals about the resources they use, the places they visit, and the orientation of environmental behaviors, as this guides the interactions with and pressures

on marine environments (McKinley & Fletcher, 2010; Mee, 2012). The integration of public perceptions of the marine environment into policy processes is highlighted in several studies (Ahtiainen et al., 2013; Gelcich et al., 2014; Jefferson et al., 2014). Studies of recreation and public awareness in countries surrounding the Baltic Sea found national differences in the level of concern among residents and highlight the importance of cultural and recreational values (Ahtiainen et al., 2013). In a cross-national study of residents in 10 European countries, Potts et al. (2016) found differences in scientific and public perspectives on the key factors affecting the marine environment and a need for developing ocean citizen initiatives and wider social engagement beyond the limited stakeholder approach including a deeper understanding and incorporation of social complexities into marine planning where communities are actively engaged in the decisions that affect them.

1.6. Public Awareness

An extensive comparative study of surveys on public perceptions of marine threats and protection finds that citizens from around the world have a clear understanding that the ocean is threatened and most support marine protected areas (Lotze et al., 2018). This information is relevant to marine managers, policy makers, conservation practitioners, and educators because it contributes to improvements in marine management and conservation programs. There is, however, still a need for increased OL, including awareness of the marine environment to change individual behaviors and regional, national increased OL and international stewardship and governance (Lotze et al., 2018). Public awareness research is a valuable contribution to raising awareness and promoting a more bottom-up approach to enhance the protection and sustainable management of the ocean.

1.7. OL Research as a Tool in Policy and Planning

OL research is an important policy tool and there is a need to test approaches and develop recommendations to support the use of OL as a practical policy tool, feeding directly into decision-making with a focus on better understanding the science–policy–society interface (McRuer et al., 2025). A more holistic approach with increased integration of local community priorities is needed, including data and documentation on public perceptions of ocean issues as part of policy and planning. Lack of user involvement and failure to incorporate diverse understandings of human–ocean relationships in marine planning may cause failure (e.g., failed marine protected areas), inadequate protections, and a lack of shared commitment to implementation (Rife et al., 2013; Turnbull et al., 2021).

1.8. Recreationists as Key Informants

Coastal and marine recreation includes direct engagement with the ocean (Kaae et al., 2018). Recreationists can offer experience-based insights into the complex interactions between human activities and marine ecosystems, thereby providing planners with more comprehensive understandings to facilitate the design of targeted policies, support conservation strategies, and foster public engagement at an early stage (McRuer et al., 2025). We perceive coastal and marine recreationists as an important group in OL as they use the marine environment to gain a range of benefits (mental and physical health, experiences, socialization, etc.), and due to frequent visits, recreationists may perceive problems not detected by planning and management.

1.9. Objective

The objective of this article is to assess public participation geographical information system (PPGIS)-mapping as a potential participatory method in OL research, focusing on knowledge exchange in the public-planning interface. Based on a Norwegian case study in the Oslo Fjord, residents' coastal and marine recreational uses, knowledge, and perceptions of their local fjord were documented, contributing to increasing OL in planning and management.

The article starts off introducing the present knowledge gaps of coastal and marine recreation data in relation to planning of the coastal and marine areas in Oslo Fjord and then presents key results of a coastal and marine recreation PPGIS-survey in the fjord. This is followed up by a discussion on how the data and mapping of coastal and marine recreation may contribute to the different dimensions of OL and the potentials and limitations of further integration of spatial data into OL research.

2. Methods

The project was carried out in 2022–2023, involving the Transport Economic Institute (project coordination), the Norwegian Sports University (qualitative interviews), and the University of Copenhagen (PPGIS-survey of resident population) based on experience from a similar mapping in Denmark (Kaae et al., 2018). This article is based on the results from the PPGIS-survey (Kaae & Olafsson, 2024), while the qualitative studies (Gurholt & Lund, 2024) are reported in other papers and a summary report (Flotve et al., 2024) combines the project's results.

The data collection of coastal and marine recreation of the Oslo Fjord used a PPGIS method, which combines a survey with spatial mapping using the Maptionnaire software (https://www.maptionnaire.com). The survey was developed by the University of Copenhagen in cooperation with the overall project group and it was pre-tested. Permission for the survey was granted by the University. The questionnaire included initial questions, consent to use the results for research purposes, and questions to sort recreational users of the Oslo Fjord from non-recreational users. The recreationists mapped their recreation sites and for each point, a range of questions were answered about activity, motives, seasonality, etc. The non-recreationists joined the recreationists in answering questions on satisfaction of recreational needs, and those with unfulfilled needs were asked questions on barriers. Finally, supplementary sociodemographic variables were included. Open-ended responses provide a wealth of qualitative information.

Data collection was conducted by a professional survey company (Norstat), which monthly distributed a link to the survey during 1 year (June 2022 through May 2023) to a representative sample of the adult population (18 years and above) in their panel. Respondents receive points for participating in different surveys. Norstat provided a number of basic socio-demographic variables of the respondents, while supplementary background variables were included in the survey. We received 14,162 fully or partially completed surveys, but we removed duplicates and surveys without consent to use the results for research purposes, as well as questionnaires with fewer than five responses. The final sample of 12,445 respondents includes both participants in coastal and marine recreational activities at the Oslo Fjord and a segment that did not use the Oslo Fjord, either because they used other recreation areas or did not participate in recreation activities. The survey is representative of the adult population (18 years and older) in the 26 municipalities bordering the Oslo Fjord by gender, age group, and municipality.

3. The Oslo Fjord Case Area and Planning Challenges

The Oslo Fjord in Norway is long and narrow in Southern Norway, involving 26 municipalities with 1.7 million inhabitants, and with the capital, Oslo, in the inner part. The fjord suffers from a range of environmental degradation (e.g., poor water quality, lack of fish, and invasive species), increasing urbanization, accessibility problems, and user conflicts. As a response, the Norwegian Ministry of Environment is preparing a comprehensive plan to reduce the problems and conflicts in the Oslo Fjord.

While natural science data on a range of ecosystem services are available and monitored over time, Chen et al. (2019) identified a lack of knowledge on the recreational uses and user conflicts in the fjord. Several reports on the environmental and economic aspects of the fjord exist, but recreation data and mapping of the many coastal and marine recreational uses of the Oslo Fjord were needed (Klima- og miljødepartementet, 2021). Some recreation data exists on specific coastal sites (Stokke & Hage, 2021), as well as for protected areas and national parks in the Oslo Fjord (Haukeland & Stokke, 2021; Meyer & Strandli, 2021), but comparable and spatial data for the entire fjord were missing. Consequently, the Norwegian Ministry of the Environment commissioned a study on outdoor recreational use of the Oslofjord including the coastal zone. The aim was (a) mapping of the coastal and marine recreational uses throughout the year of the Oslofjord, (b) Mapping of what enhances and limits the recreational use by different groups in the population, and (c) mapping of conflicts among recreation groups and in relation to other users of the fjord.

3.1. Integration of Coastal and Marine Recreation in the Current Comprehensive Plan of the Oslo Fjord

In the process of establishing a comprehensive plan for the Oslo Fjord, the Norwegian Ministry of Environment, as the planning authority, already has access to a range of well-documented biological and commercial sector data. The lack of knowledge and spatial data on the recreational uses of the Oslo Fjord (Chen et al., 2019; Klima- og miljødepartementet, 2021) was a challenge. These data-needs motivated the commissioning of the present study in the densely populated region with many competing uses.

The study focused on providing key information on coastal and marine recreation to the planning process, and we see some potential in the methodological approach and integration of local resident perspectives and experience-based knowledge that may be relevant to OL studies and to bridging some of the gaps between the theoretical and applied knowledge in spatial planning. Shellock et al. (2024, p. 10) highlight the application of OL in decision-making processes and identify:

> A need for greater collaboration between researchers, policymakers, and stakeholders to develop practical guidance on integrating OL into marine policy and management frameworks. This collaborative approach can help bridge the gap between scientific knowledge and governance, facilitating the translation of OL concepts into actionable strategies for sustainable Ocean and coastal management.

The Norwegian Ministry is presently working on the comprehensive plan for the Oslo Fjord and the recreation data and mapping are in the process of being integrated into the planning process. Results of the study are published in an extensive Nordic language report and have been presented to planners, stakeholder groups, and the public on several occasions. Several local planning authorities have shown great

interest in the data and mapping covering their county or municipality for their planning and management. We see relevant application of PPGIS-mapping as a potential participatory method in OL, focusing on knowledge exchange in the public-planning interface.

4. Selected Results

The results provide a wealth of quantitative and qualitative data on recreational uses combined with geolocated and scalable spatial mapping. For detailed descriptions and maps, see Kaae and Olafsson (2024). Here, selected results will be presented with a focus on the experience-based mapping by recreationists of different problems to be addressed in planning and management.

Results show that the Oslo Fjord is a popular recreation site: 71% participated in fjord-oriented recreation activities annually, 67% participated in land-based coastal outdoor recreation activities, and 53% in marine outdoor recreation activities. As only non-motorized and non-competitive activities are perceived as outdoor recreation in Norway, the study does not include activities by the 31% who sailed with ferries to recreation areas, the 28% who sailed in motorboats or used jet skis, or the 7% who participated in water sports or competitive activities. A different definition of outdoor recreation may be used in other countries.

Data was collected on the different activities, motives, number of visits, organization of visit, seasonality, perceived health benefits, fulfilment of recreational need, and overall satisfaction with visiting the fjord, as well as a range of socio-demographic variables. Furthermore, non-participants and participants with unfulfilled recreation needs were asked questions on barriers to participation.

4.1. Mapping

The mapping involved mapping of coastal and marine recreation activities and mapping of perceived problems with access, environment, and other users.

As seen below, both coastal recreation activities (Figure 1) and marine recreational activities (Figure 2) are concentrated in the inner parts of the Oslo Fjord, where the capital, Oslo, is located.

For the coastal recreation activities, the most popular is walking under three hours (29%); stays with a focus on quietness, reflection, looking at the view, and experiencing nature (12%); bathing/winter bathing (11%); stays with a focus on sunbathing, picnic, BBQ, etc. (9%); dog walking (7%); and walking over three hours (6%); 3% participate in nature studies (photography and drawing/painting), 2% are fishing from land, while 1.3% participate in beach clean-up (plastic, invasive Pacific oysters, etc.). Many open responses mention the decline in water quality, lack of fish, etc. The most popular marine recreation activities are bathing/swimming from boat (47%), paddling/rowing (kayak, canoe, SUP, rowboat, etc.; 13%), fishing from boat (12%), ice-bathing/winter bathing (9%), sailing (non-motorized; 9%), nature studies from boat (5%), and clean-up of the fjord environment (2%). Seasonality differences show that most marine activities take place during the summer, while land-based activities are less influenced by weather conditions and take place throughout the year.

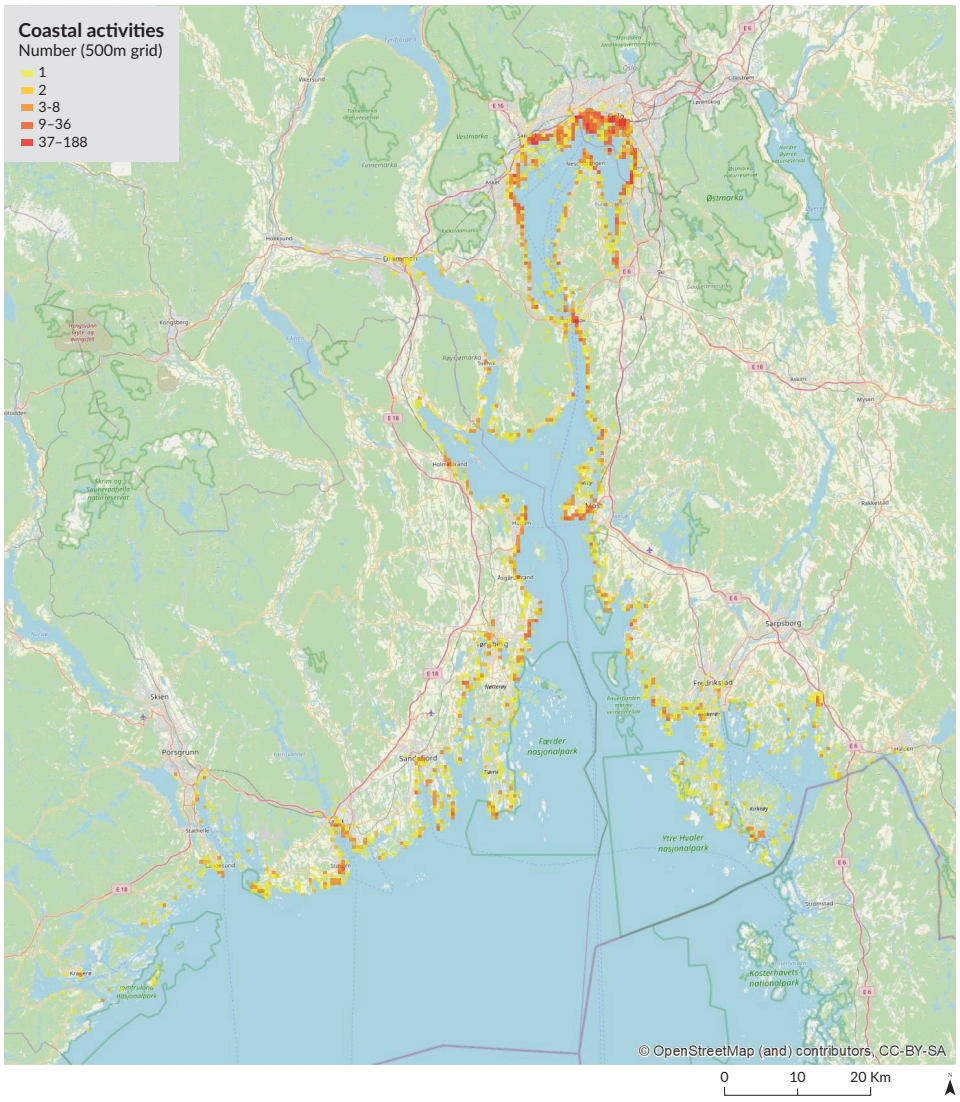

Figure 1. Coastal recreation activities (4.933 respondents mapped 6.713 points with 15.124 recreation activities).

Both recreationists and non-participants in recreation were asked to state their level of fulfillment of recreation needs. Many had their recreational needs fulfilled by either participating (27%) or not participating (11%) in coastal and marine recreation in the Oslo Fjord, while just below half (48%) had some level of unfulfilled needs for participating as much as they would like to, and 14% did not answer. The group with unfulfilled recreation needs was asked questions on barriers following the framework of Crawford et al. (1991). While some barriers related to the supply-side (e.g., amount and quality of recreation facilities) may be addressed in planning, many of the barriers were linked to the personal life situation of respondents and constraints of intra-personal, interpersonal, or structural constraints, which can be difficult to address in planning. Many constraints were linked to limited time, family obligations, and health problems. Also, 14% had either permanent or temporary reductions in functions that call for facilitating access for all through universal design.

Participation in coastal and marine outdoor recreation in the Oslo Fjord was higher among respondents with higher education, persons with higher household income, and in families with children in the household.

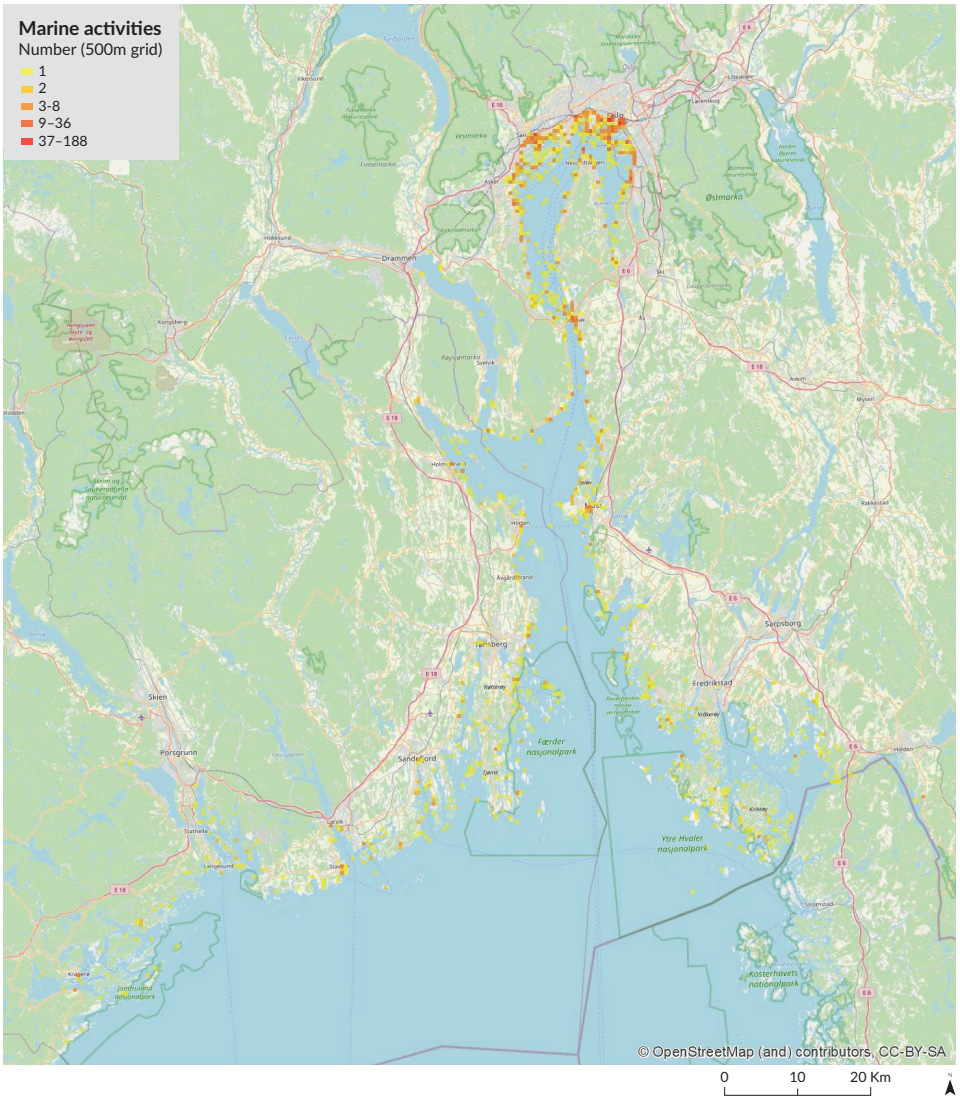

Figure 2. Marine recreation activities (1.711 respondents mapped 1.913 points with 2.375 recreation activities).

No gender difference was found in the overall participation in recreation, but differences emerged in specific recreation activities—for example, more men participated in motorized water sports. Participation was lower among the oldest age group and in non-Western ethnic groups.

Most of the recreationists reported self-perceived benefits from their fjord-oriented recreation activities on their psychological wellbeing and mood (82%), overall life quality (68%), their physical health condition (58%), and their social life (51%). Open-ended statements expressed many experiences of these benefits and emotional bonds with the fjord.

4.2. Problem Mapping

To inform planning, the study also included mapping of perceived problems in the fjord. Among the recreationists who mapped recreation activities in the Oslo fjord, 27% mapped areas where they perceive

problems. This includes 757 points where they perceived accessibility problems, 593 points with perceived environmental problems, and 345 points with perceived problems with other users. These are further described in Sections 4.2.1–4.2.4, and illustrated by the mapping.

4.2.1. Access Problems

The problem mapping shows that residents perceive problems related to accessibility both in the inner urban part of the fjord but also in many coastal areas along the less populated parts of the fjord (Figure 3). For each point, respondents could indicate further details of different access problems and the magnitude of the problems. As seen in Figure 4, most access problems are linked to trails being closed off, people being unsure if they are allowed to trespass, and attempts at privatization. About a third avoid visiting these areas, hereby indicating displacement of those perceiving the most access problems.

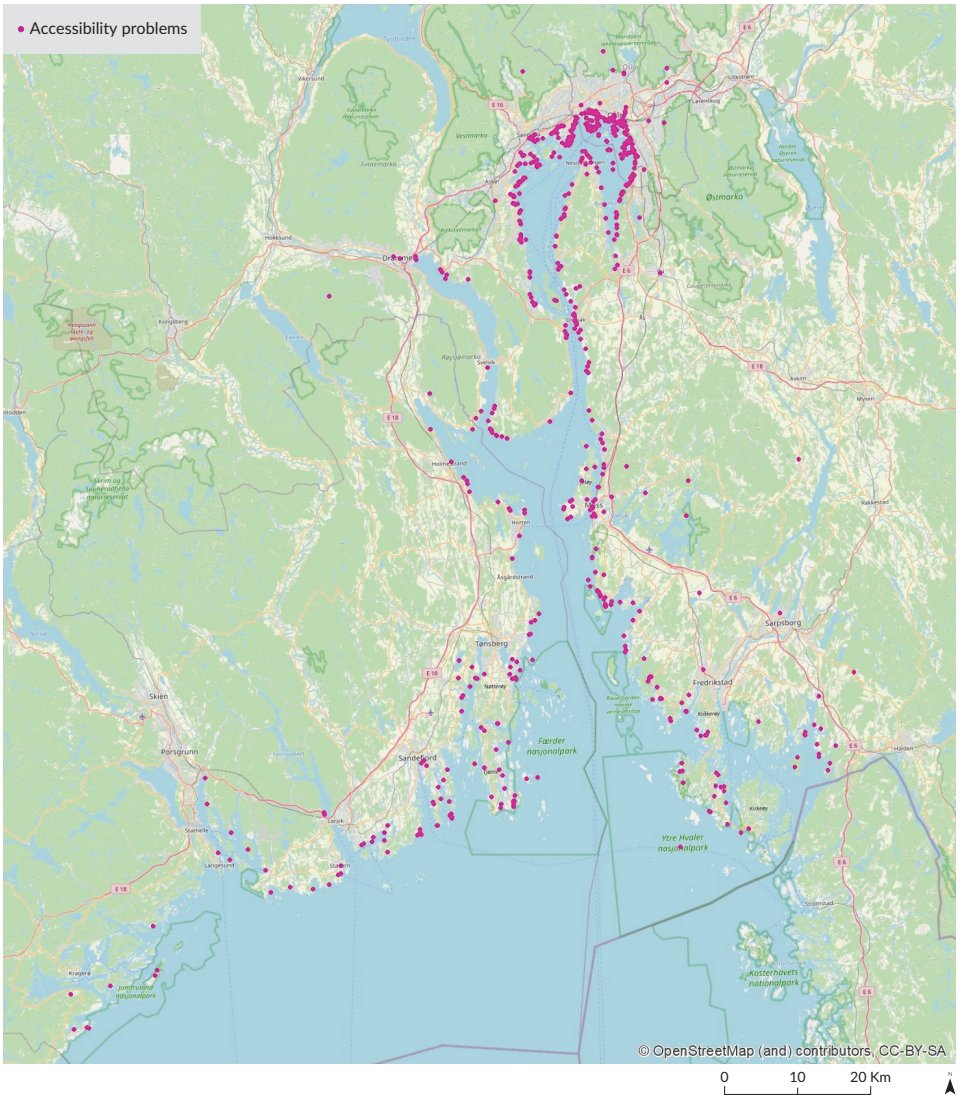

Figure 3. Mapping of problems with access to the fjord perceived by recreationists in the Oslo Fjord (757 sites mapped).

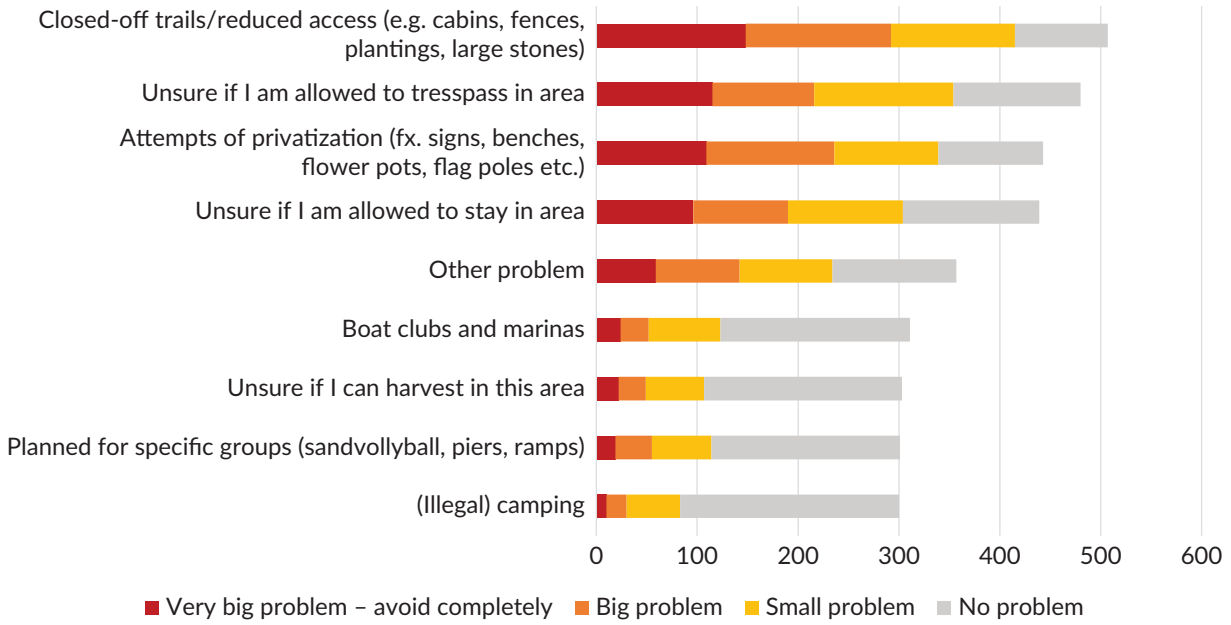

Figure 4. Perceived problems of access. Note: 620 residents mapped 757 points, representing 3,441 accessibility problems.

4.2.2. Perceived Environmental Problems

The "problem mapping" shows that residents also perceive environmental problems in the fjord. As seen in Figure 5, there is a wide distribution of perceived environmental problems both in the inner part of the fjord and along the shores. For each point, respondents could indicate further details of different environmental problems and the magnitude of the problems. Key problems are linked to the water quality, litter, and noise (Figure 6).

4.2.3. Problems With Other Users

The mapping (Figure 7) shows that many problems with other users are perceived in the inner part of the fjord. For each point, respondents could indicate further details of different problems with other users and the magnitude of the perceived problems. This corresponds well with crowding being the most experienced problem with other users (Figure 8), followed by noise from other users, large groups occupying areas, and noise from motorized boats and jetskies. A smaller part completely avoids the mapped areas, which indicates displacement.

4.2.4. Detailed Mapping

The GIS data is scalable, and the maps show the island Jeløy with examples of open-ended questions with detailed information on specific problems and user-generated suggestions on solutions (Figure 9a, b, c, and d). The mapped points provide key information for local planning and management.

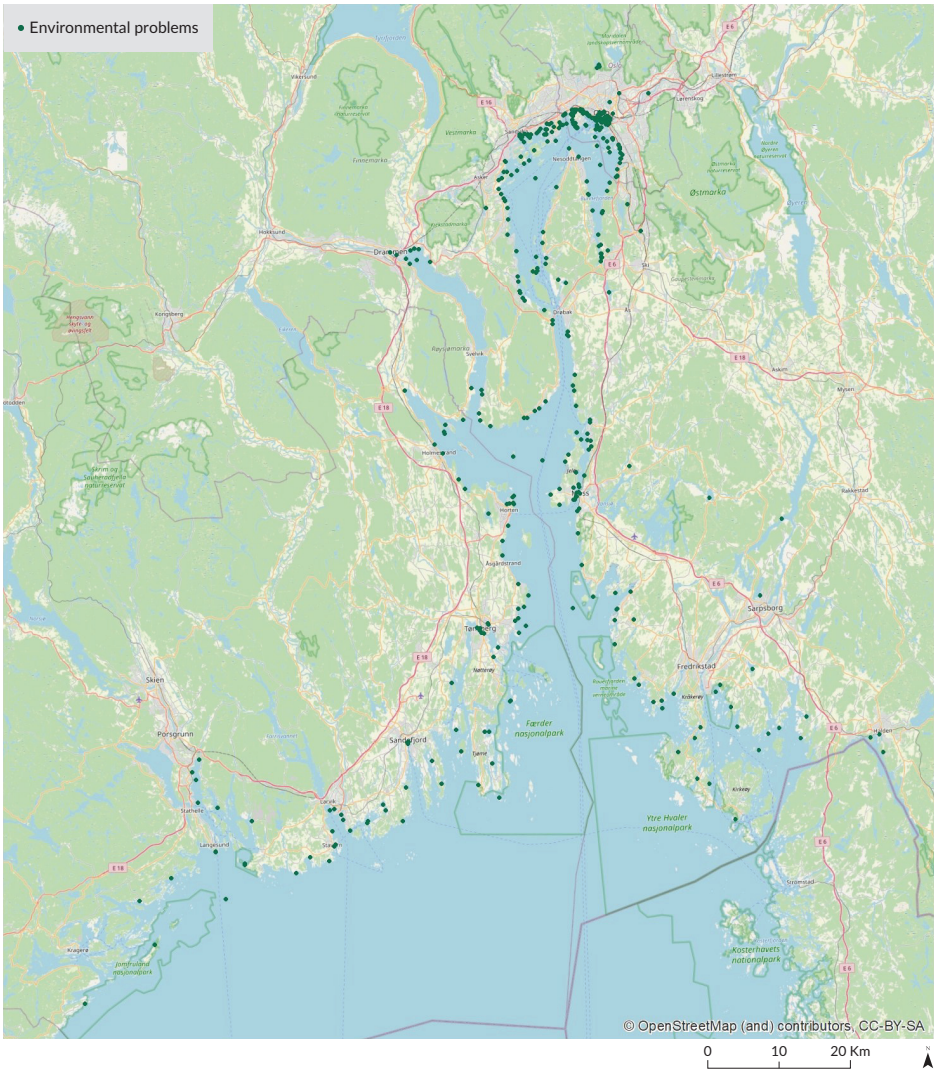

Figure 5. Mapping of environmental problems perceived by recreationists in the Oslo Fjord (593 mapped points).

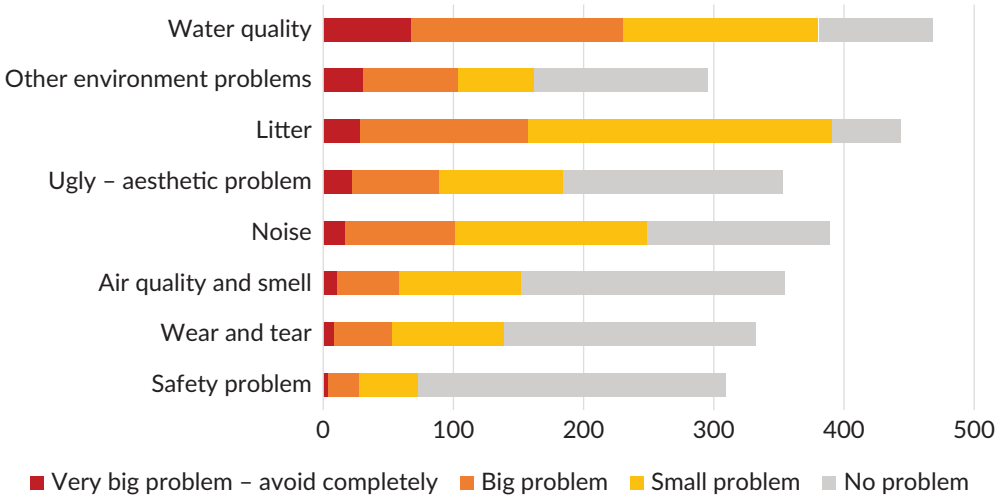

Figure 6. Perceived environmental problems. Note: 536 residents have mapped 593 points, representing 1728 problems.

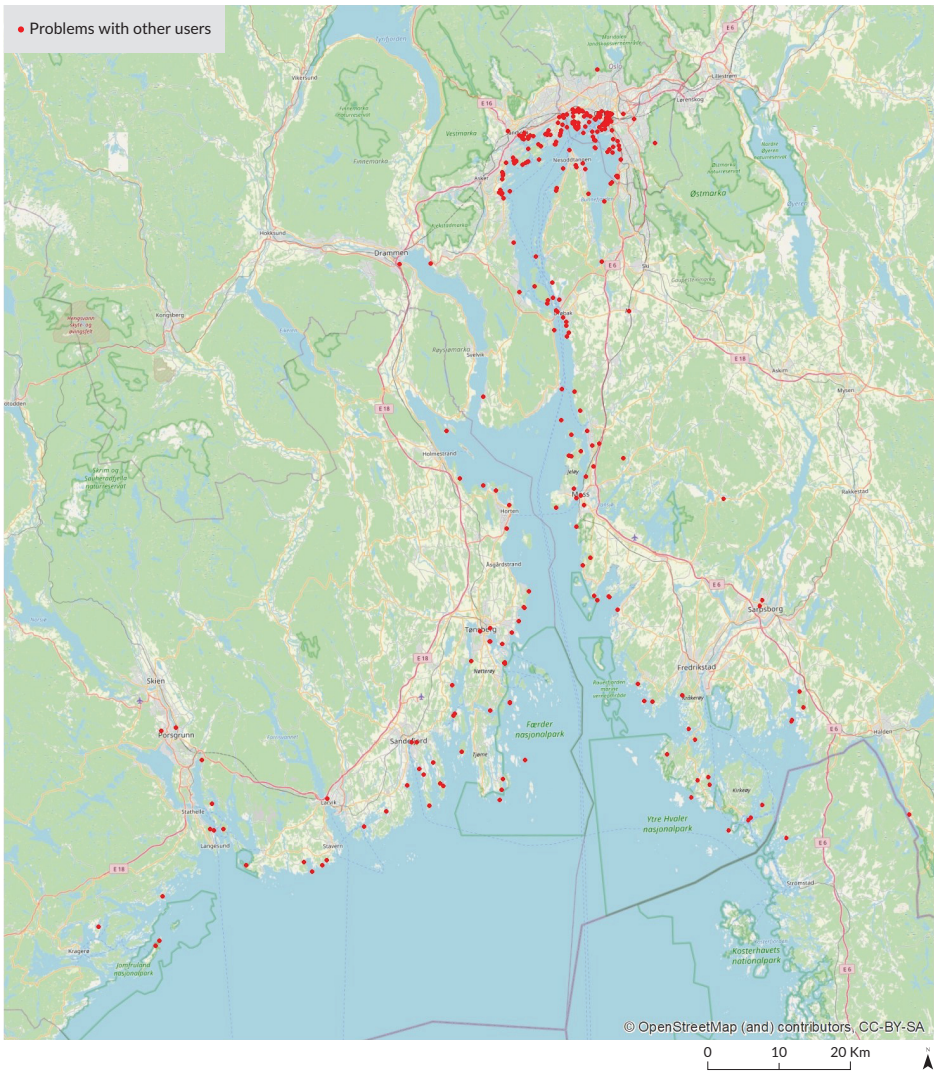

Figure 7. Mapping of perceived problems with other users (345 mapped points).

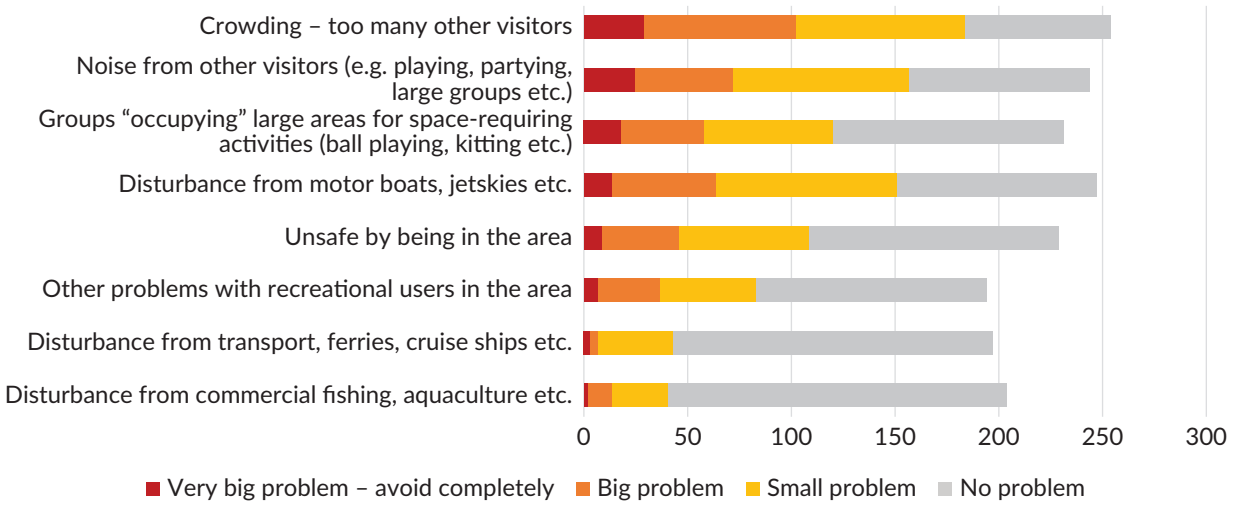

Figure 8. Perceived problems with other users. Note: 299 respondents mapped 345 points, representing 1800 problems.

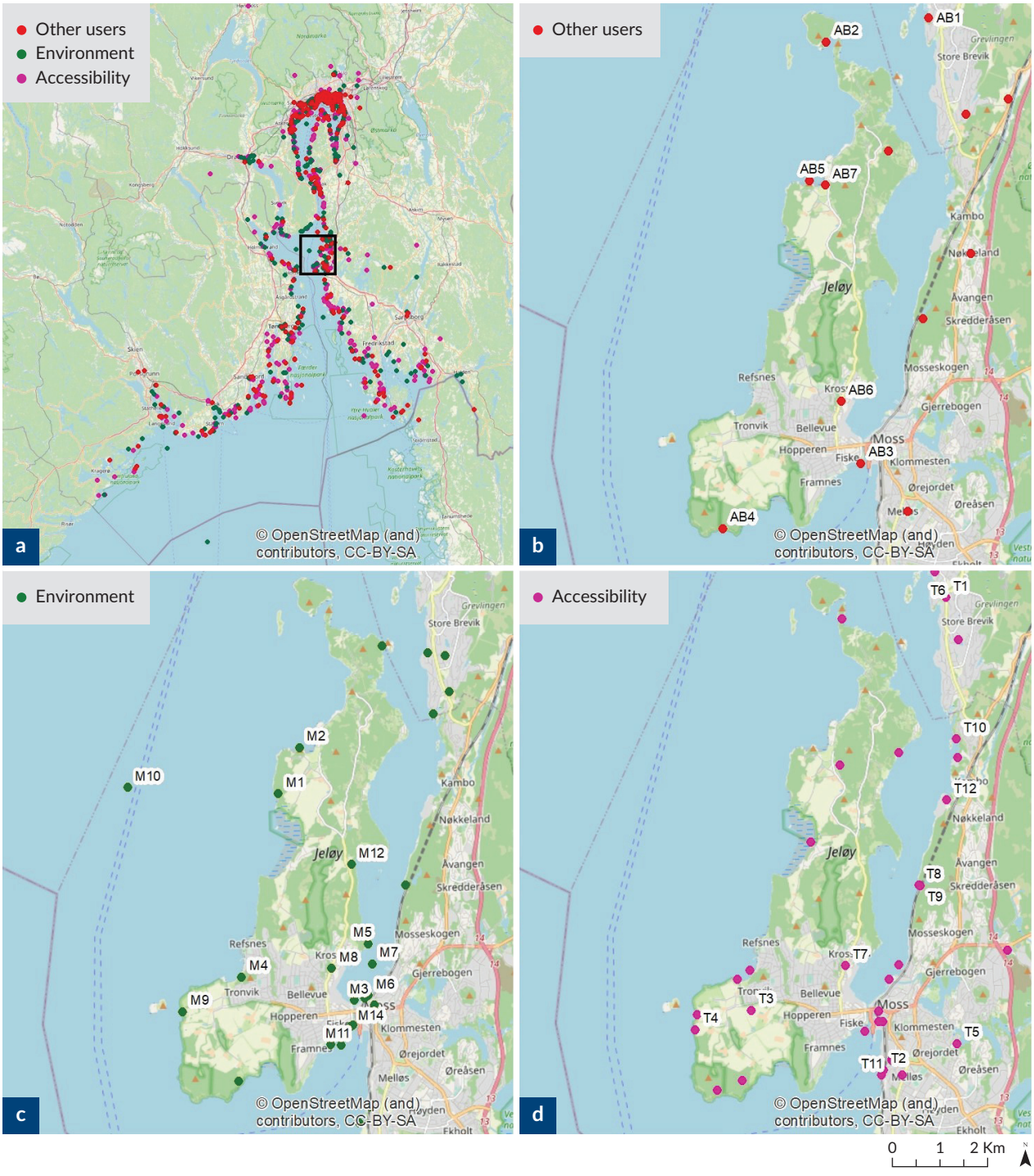

Figure 9. (a) Perceived problems in the Oslo Fjord; (b) perceived problems with other users at Jeløy; (c) perceived environmental problems at Jeløy; and (d) perceived access problems at Jeløy.

5. Discussion

5.1. How the Study Contributes to the 10 OL Dimensions Among Residents, Planners, and Managers

The project aimed at collecting data on resident recreational uses of the Oslo Fjord for planning purposes. However, as recreationists are frequent and engaged users of the Oslo Fjord, we see their use patterns, experience-based knowledge, and perceptions of problems as highly relevant to OL. By filling in the questionnaire, the respondents needed to reflect on their use of the coastal and marine environment, but also got the opportunity to share their experiences, perceptions, concerns, and suggestions with the planning authorities. The response process may increase the awareness dimension of OL among respondents.

While surveys are the most used method in OL research (Shellock et al., 2024), PPGIS-mapping adds an additional level of spatial knowledge generated by public participation, and the method may have wider application as a tool in OL research—not only in relation to planning and management.

Table 1 is a summary of how we see the study contributes to the 10 dimensions of OL (Brennan et al., 2019; McKinley et al., 2023) in the public-planning interface. Some of the 10 OL dimensions are more involved than others in this exchange process, for example, knowledge, access, experiences, (recreational) behavior, and communication, while expressions in the open-ended responses contribute to the emOcean dimension. The OL dimensions of attitude, awareness, and behavior change in general are more indirectly reflected but could be included more explicitly in future studies. The tool provides detailed mapping and data of high trust and transparency and results with high capacity for being adapted into planning and management. The adaptability also applies to the flexibility of the tool and the potential for including questions covering all 10 OL dimensions in future studies.

Table 1. Summary of the exchange within each of the 10 dimensions of OL between residents and planners and managers and the possible implications for the planning process for the Oslo Fjord.

Dimensions of OL	Residents provide	Planners and managers receive	Implications for planning
Knowledge	Sharing experience-based knowledge on recreational uses and perceptions of the Oslo Fjord	New experience-based knowledge on socio-cultural aspects added to environmental science-based knowledge	Potential for inclusion of social dimensions into planning
Access and Experience	Many problems of access identified—physical access and access to knowledge. There is a distance-decay function in visitation and consequently in experiences of the Fjord Non-user barriers to participation were identified	PPGIS-mapped perceived problems of access, environmental problems, and user conflicts Descriptions and user-generated suggestions on improvements	Opportunity to locate and reduce access barriers and improve experiences by more connected trails and upgrade of facilities, better public transport, and more parking Universal design of trails and facilities to increase access for all. Information campaigns

Table 1. (Cont.) Summary of the exchange within each of the 10 dimensions of OL between residents and planners and managers and the possible implications for the planning process for the Oslo Fjord.

Dimensions of OL	Residents provide	Planners and managers receive	Implications for planning
Attitude	Overall satisfaction with the visit was included as was self-selected displacement Some socio-cultural differences in use in relation to ethnicity, education level, income level, children in household, and age but not gender	Increased focus on the inclusion of all groups by planners and managers Focus on low satisfaction and displacement (who, where, and why)	Attention to factors causing low satisfaction and displacement Social programs for inclusion
EmOceans	Many expressions of emotional bonds with the Fjord (long qualitative statements in open-ended responses) Positive praise of fjord experiences and memories of good times Mourning of loss of marine life, fishing opportunities, and decline in other recreational qualities	Increased understanding of the personal and emotional importance of the Oslo Fjord to people's lives	Sites or aspects of high emotional importance to people may be considered/restored in the comprehensive plan
Awareness	Residents' awareness of the many problems of the Fjord (especially with access and water quality) have been identified Perceived health benefits identified	Heightened awareness in planning and management of resident perceptions of benefits and problems	Increase awareness in the comprehensive plan of "problem areas" for recreation, including areas people have stopped visiting due to problems (displacement)
Communication	The survey itself may be viewed as a communication tool to increase dialogue between residents and planners Representative of a broader segment than specific interest groups	Results are communicated in reports (free download), presented online, at several national and international conferences, in newspapers, and in radio interviews	Continued communication of recreational perspectives in the comprehensive planning process and public consultation
Behavior	Mapping and data on recreational behavior such as activities, motives, seasonality, group structure, etc No direct effect on the behavior of residents at this point, but potentially after planning initiatives	Spatial patterns of different recreational behaviors and a nuanced understanding of the different recreational user groups	GIS-based mapping of recreational use patterns can be combined with environmental data and maps of other uses (e.g., commercial fishing, shipping, etc.)

Table 1. (Cont.) Summary of the exchange within each of the 10 dimensions of OL between residents and planners and managers and the possible implications for the planning process for the Oslo Fjord.

Dimensions of OL	Residents provide	Planners and managers receive	Implications for planning
Activism	Few examples identified, but some landowners try to prevent recreational access by illegal signs, fences, etc.	Sites with experienced problems of recreational access are mapped and can be addressed in planning The type and magnitude of the access problem are described for each mapped site	Planners and managers can address the problem sites in the comprehensive planning process
Trust and transparency	The representative and large sample (12,445 responses) of the adult population in 26 municipalities makes the results trustworthy The method and results are transparent	A solid and trustworthy dataset is a prerequisite for inclusion in planning and the GIS data makes spatial analyses possible The voices of the general public, rather than specific interest groups	All data, including GIS data, has been delivered to the Norwegian Ministry of the Environment for integration into planning—open access by request
Adaptive capacity	The survey instrument can be adapted to diverse topics and knowledge needed from residents or from other groups	The integration of the extracted knowledge into planning and management depends on the planning regime and engagement by planners and managers at different levels	Adaptation of coastal and marine recreation data and problem-mapping into the comprehensive plan is likely, as the Ministry initiated the project

The article addresses the geographical and linguistic imbalances in OL literature as it provides insight into the results of an otherwise "grey literature" in non-English language. Likely, many similar studies could add to the growing body of OL literature. But in planning, many data collections are of an applied nature and disseminated in local language reports to planning and management agencies with limited interest in funding academic publications.

In the Ocean Decade, the role of OL is increasing as a tool for society engagement and community involvement (Claudet et al., 2020; UNESCO, 2024). OL is an evolving concept, and we introduce the geospatial mapping of social perspectives of the Ocean as a relevant tool in relation to integrating OL into a spatial planning and management context and to supplementing the predominant scientific knowledge with social perspectives on the ocean. By involving a large population sample, it also functions as a tool for community engagement beyond the select stakeholder groups and provides a wider societal involvement.

The study adds experience-based knowledge of recreational users to the existing natural science data and contributes to a broader knowledge base. This may support a more collaborative approach to help bridge the gap between scientific knowledge and governance and facilitate the translation of OL concepts into actionable strategies for sustainable ocean and coastal planning and management. The involvement of a wider community may also enhance the acceptance and effective implementation of OL initiatives by fostering greater participation and ownership among coastal communities in ocean and coastal management

processes (Shellock et al., 2024). Increased integration of local community priorities by including data and documentation on public perceptions of ocean issues is an important part of a more holistic approach to policy and planning. We perceive coastal and marine recreationists as an important user group and key informants in OL, as they frequently use the coastal and marine areas and may experience different problems not detected by planning and management.

5.2. Potentials for Further Integration of the PPGIS Results Into Planning

Data and mapping on resident recreational uses of coastal and marine areas may have further potential for being part of planning and analyses. Experiences from a nationwide PPGIS-mapping in Denmark (Kaae et al., 2018) showed a wide range of applications. At the national level, spatial data was used to compare the distribution of recreation in relation to waterbirds at different seasons (Laursen et al., 2021), recreation data was used alongside natural science data in an extensive modelling of ecosystem components and pressures for all Danish waters in the ECOMAR-project (Andersen et al., 2020a, 2020b) and in analyses of the compliance with different directives (Andersen et al., 2023). The recreational data was delivered to the Danish planning authorities responsible for the maritime spatial planning (Olafsson & Kaae, 2019), but it is only a service layer in the plan. At the regional level, the data were integrated into multisectoral projects on maritime spatial planning in Øresund (Riemann, 2019) and Kattegat (Riemann et al., 2020). At the local level, the recreational data was used in local national parks planning (Olafsson et al., 2016) and in the assessment of recreational uses in the western part of the Limfjord when planning a new watersports center (Kaae & Olafsson, 2020).

In Norway, the Oslo Fjord recreation data may, in similar ways, be used in new projects beyond the comprehensive plan. Knowledge and data diffusion into projects on environmental accounting (MAREA project) is ongoing and in integrated environmental assessment and synthesis (AquaSYNC, ongoing). Several local and regional planning authorities are interested in extracting data and maps covering their areas of planning.

In future studies, we see the potential for including more OL-related dimensions such as knowledge of the sea, nature connectedness, place attachment to coastal/marine sites of special emotional meaning, etc. The method may also be applied in more OL-focused studies of populations or groups. Adding a mapping component to the survey instrument has the advantage of providing spatial GIS-mapping of social science data, such as experience-based knowledge, activities, etc, which makes it compatible with other data layers in spatial planning, including natural science data on the environment.

Drawbacks are the need for a license for a PPGIS program and the potentially high cost of data collection (e.g., through a professional data collection company) to obtain a representative sample of the population. GDPR rules may make data collection difficult, e.g., through recreation organizations. While open-ended questions provide a wealth of information, it is very time-consuming to analyze thousands of responses and more quantitative measurements may be included. A large sample is needed to get reliable spatial mapping in the least populated areas, in particular when there is an uneven distribution of the population, as in the Oslo Fjord.

6. Conclusion

A large part of the population participates in coastal and marine outdoor recreation and thus gets in close contact with the coastal and marine environment and perceives both benefits and problems. Their experience-based knowledge provides valuable insights, complementing the science-based data in policy, planning, and management of the Oslo Fjord. This article illustrates how this may contribute to the 10 OL dimensions and knowledge exchange in the public planning interface.

The public participation mapping approach is a highly relevant tool providing new knowledge for planning and increasing the OL level among planners, managers, and policy makers in the Oslo Fjord case area and likely also among the residents who must reflect on their relations with the Oslo Fjord, describe their activities, benefits, and perceived problems.

The project provides both quantitative and qualitative data on many of the 10 OL dimensions. It reflects new insight into the perceived health benefits as well as experienced problems with access, environment, and other users, detailed descriptions, and user-generated suggestions for improvements—highly relevant for planning. Adding geospatial mapping data to OL surveys and the wider concept and field of OL research may provide new insights and understanding of OL dimensions and how social science may contribute to more sustainable ocean policy, planning, and management.

Overall, this study in coastal Norway helps to demonstrate how the PPGIS-mapping approach can be used as a tool for coastal and marine management and planning and how, more broadly, PPGIS-mapping can be used to increase OL among community members, planners, managers, and policy makers.

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Conflict of Interests

In this article, editorial decisions were undertaken by Emma McKinley (Cardiff University, UK), Benedict McAteer (Queen's University Belfast, UK), and Brice Trouillet (Nantes Université, France).

Data Availability

A link to the report in Danish language on the PPGIS study of outdoor recreation activities in the Oslo Fjord, including the coastal zone, can be found here: https://www.miljodirektoratet.no/publikasjoner/2024/mai-2024/ppgis-undersogelse-af-udendors-fritidsaktiviteter-i-oslofjorden-inkl.-strandzonen

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Ocean XR: A Deep Dive Into Extended Reality for Marine Education and Ocean Literacy

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Abstract

Contact with the ocean is key to improving ocean literacy (OL)—the understanding of our influence on the ocean and the ocean's influence on us. Ocean extended reality (ocean XR) can contribute to marine education and OL by simulating marine environments using augmented, mixed, and virtual reality technologies. To better understand this emerging field, we analyzed 94 experiences revealing insight into the usage and effects of key extended reality features: presence, interactivity, and embodiment. Virtual wildlife was present in over 75% of content, though wildlife interactions were less common (42%) than interactions with the environment (72%). Embodiment was featured in 49% of experiences, and 30% placed users in a scientific role. Most simulations (88%) featured at least one OL principle, with correlations suggesting positive relationships between OL principles and key features. This work represents a first step in understanding how ocean extended reality can benefit marine education and OL and offers suggestions for creating more impactful virtual ocean experiences.

Keywords

augmented reality; extended reality; immersive technologies; marine environmental education; mixed reality; ocean literacy; virtual reality

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1. Introduction

Human communities benefit from the ocean, which harbors marine biodiversity that supports fishing, tourism, and pharmaceuticals (Malve, 2016). The ocean also buffers the global climate and provides extensive economic resources through shipping, aquaculture, minerals, and energy creation (OECD, 2016). Beyond this service-based approach, it is our duty to care for marine ecosystems as part of the legacy we borrow from our children (Na'puti, 2023). However, ocean resources are degrading from human activities through habitat destruction, overfishing, pollution, and the effects of climate change (Heinze et al., 2021). The UN Decade of Ocean Science for Sustainable Development (2021–2030) calls for "an inspiring and engaging ocean where society understands and values the ocean in relation to human well-being and sustainable development," an outcome that "can be achieved through ocean literacy approaches" (UNESCO-IOC, 2021, p. 19) The concept of ocean literacy (OL) relates to one's ability to understand their influence on the ocean and the ocean's influence on them (Cava et al., 2005). While OL was defined 20 years ago to address the lack of ocean-related content in US schools, it has since become a global movement to improve our relationship with the ocean.

The nature of the ocean makes it difficult to experience or understand, as only people living near coastlines see the ocean on a regular basis (Fauville, McHugh, et al., 2018). Even for these people, most of the ocean is still inaccessible below the surface and beyond the coast. Digital technologies can be valuable when interaction with the natural world is impossible or when an invisible phenomenon needs to be made more tangible. While the remote nature of the physical ocean cannot be changed, immersion in and experience with the ocean can be mimicked with immersive media. Extended reality (XR) modalities like augmented, mixed, and virtual realities have unique affordances that simulate experiences more effectively than videos on screens (Bailenson, 2018). This capability is determined in part by the specific XR modality's placement along the spectrum of virtuality, a continuum articulating the extent to which digital content coexists and/or replaces the physical world (Figure 1):

- Augmented reality (AR) enriches the physical space observed through the camera of mobile devices by superimposing digital content such as 3D objects, text, and sound.
- Mixed reality (MR) uses see-through head-mounted displays (HMDs) to integrate digital content naturally into the physical world.
- Virtual reality (VR) requires an HMD that visually isolates the user from the physical world and immerses them completely in a virtual environment.

In XR, users can interact with the content and visualize invisible concepts (e.g., molecules). VR has shown potential to promote pro-environmental behavior (Plechatá et al., 2022; Stenberdt & Makransky, 2023), nature connectedness (Breves & Heber, 2020), and knowledge gain (Markowitz et al., 2018). However, more research is needed to understand how XR can improve marine environmental education and promote OL. This study contributes to those goals in two ways. First, we identified the existing XR content related to the ocean (called ocean XR experiences or ocean XR content hereafter). Second, we conducted a content analysis of these ocean XR experiences to form an initial understanding of their (a) product information, (b) unique design features, and (c) contributions to OL. This analysis is crucial to identify key features and challenges to drive future research and best practices (Stephens et al., 2017).

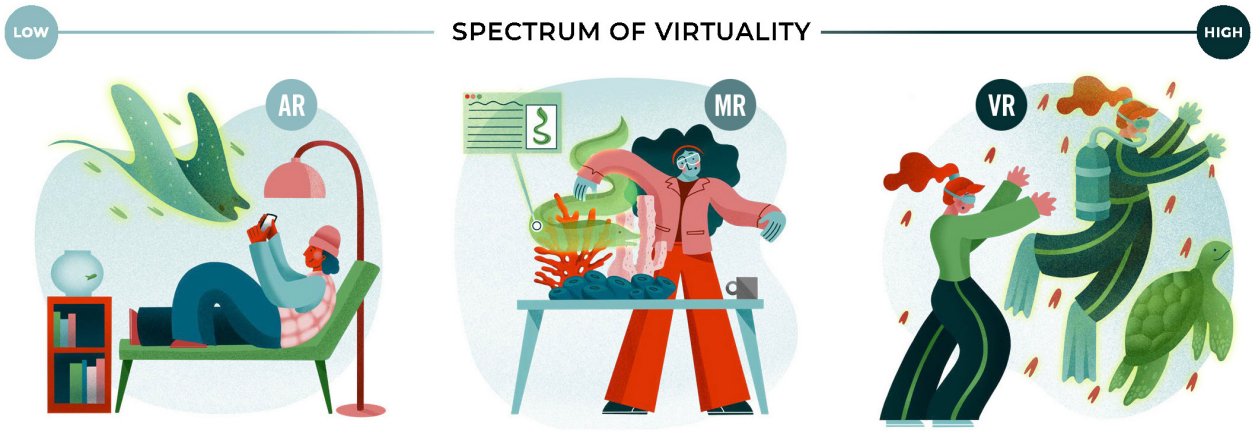

Figure 1. Spectrum of virtuality: demonstrating AR, MR, and VR. Note: Illustration by Halsey Berryman. Source: Pimentel et al. (2022).

2. Theoretical Background

2.1. The Landscape of Ocean XR Content

Ocean XR experiences exist in the wider context of the XR landscape, influenced by creator and user communities as well as economic forces, international participation, and technological advancements. The current study therefore seeks to understand ocean XR's place within XR content through variables including release year, XR modality, price, presence or absence of in-app purchase, entity responsible for the content, name of the developer, countries involved in the creation of the content, languages in which the content of the XR experience is available, and hardware on which the content is available.

2.2. Ocean XR Affordances

In XR technologies, the coexistence—or replacement—of the real world with digital content results in experiences that are immersive and feel realistic (Cummings & Bailenson, 2016). This perceptual similarity between XR-based and real-world experiences is driven by four key affordances that guided the choice of variables we coded each ocean XR experience for: interactivity, spatial presence, social presence, and body transfer.

Interactivity is defined as a system's capacity to enable users to modify aspects of a simulated experience and is known to mediate human responses to content in various contexts (Kalyanaraman & Wojdynski, 2015). XR facilitates experiences that enable rich information exchanges in part due to its capacity for natural interactivity (Lege, 2024). It is integral to understand interactive features across XR content given their capacity for shaping cognitive and affective responses. For example, one unique interactive property in XR is its degrees of freedom (DoF), which determines a user's interaction levels: 6 DoF allows full spatial exploration, while 3 DoF restricts to pitch, yaw, and roll. Interaction with the natural environment, or with environmental issues, is key for environmental education as it promotes pro-environmental concerns (Hinds & Sparks, 2008), attitudes and behavior (Bergquist et al., 2019), along with environmental risk perception (van der Linden, 2015). To investigate the role of interactivity in ocean XR content, we coded the DoF of XR content, the interaction with wildlife, and environmental interaction.

Spatial presence is a feeling of being physically located in the virtual environment. The perceptual similarity between XR-based and real-world experiences is rooted in the XR's ability to elicit a genuine sense of spatial presence (Steuer, 1992). Physical distance can be a barrier to experiencing and understanding natural environments. XR tools can create digital experiences that feel realistic, where one experiences spatial presence. To investigate aspects of spatial presence in ocean XR content, we coded for the presence of wildlife and depiction of environmental issues.

Social presence is defined as the subjective sense of being with other characters (human- or computer-controlled) in a mediated environment (Oh et al., 2018). XR can create a sense of proximity to mediated others, reducing psychological distance and increasing identification with them (Pimentel & Kalyanaraman, 2022). Identification refers to the extent to which a user perceives a social referent as self-similar, a factor shown to increase learning outcomes such as self-efficacy (Peng, 2008) and motivation (Birk et al., 2016). To investigate social presence among ocean XR content, we investigated multiplayer functionality, meaning the option to interact with other users in the experience.

Body transfer is the illusory sense of ownership over one's virtual body achieved via correspondence between the user's physical and virtual body movements (Botvinick & Cohen, 1998; Slater et al., 2010). Embodied cognition theory argues that cognition is a product of an individual's (virtual) body and its relationship to the (virtual) world (Shapiro & Stolz, 2019). XR's capacity for embodiment of virtual characters (avatars), therefore, can enhance user learning and engagement (Scavarelli et al., 2021) through various means, including simulated (direct) interactions with subject matter that constitutes experiential learning and encourages heightened attention on learning. For example, users' physical movements can promote understanding of abstract concepts in science, technology, engineering, and math (STEM) education (Kang et al., 2021). The role of XR for STEM education through embodiment has therefore been of significant interest to educators and researchers. Pimentel and Kalyanaraman (2022) invited students to become paleoclimatologists in VR and observed increases in positive views of science—and of becoming a scientist—across gender and race, with the most prominent increases in female and African American students. In another study, the user takes on the role of a professional rehabilitating oil-covered penguins in AR, leading to increased connectedness with the animals (Pimentel, 2022). Further studies have investigated how stepping into the shoes of a marine scientist, interacting with CO_2 molecules, and performing a species count in an acidified ocean environment can contribute to learners' self-efficacy (Queiroz et al., 2023) and knowledge gain (Markowitz et al., 2018). To address body transfer in the ocean XR content, we coded for embodiment and taking on a STEM or expert role.

2.3. OL Principles Addressed in Ocean XR Experiences

The OL movement, composed of policymakers, scientists, educators, and education researchers, started in the early 2000s to address the lack of marine-related content in formal US science education. They sought consensus about what people graduating from high school should understand to be considered ocean literate. This resulted in 7 overarching ideas, called the essential ocean literacy principles (OLPs; Figure 2) and 45 fundamental concepts that support and add details to the OLPs (National Oceanic and Atmospheric Administration, 2024). To investigate how ocean XR content contributes to OL, we identified which OLPs were addressed in each ocean XR experience.

Figure 2. The seven OLPs. Note: See National Oceanic and Atmospheric Administration (2024), for a list of the seven OLPs and their 45 fundamental concepts.

2.4. Relationship Between OLPs and Ocean XR Features

The interplay between technological features and educational content is important to understand learning outcomes in any mediated form of communication (Choi & Baek, 2011). Since each OLP addresses a distinct topic related to the ocean, some XR features—like interactivity, social presence, and body transfer—might be more suitable for certain principles than others. XR researchers have begun exploring the features of these tools for learning (Pimentel & Kalyanaraman, 2022; Scavarelli et al., 2021), and marine education researchers have investigated methods for teaching OLPs (e.g., Boaventura et al., 2021) and measuring OL among learners worldwide (Fauville, Strang, et al., 2018). To our knowledge, no work has been done to assess how XR and OL relate to each other. We therefore sought to explore the alignment of these key XR features with the OLPs, namely, whether there were associations between design features of immersive media and particular OLPs.

3. Materials and Methods

To better understand the ocean XR landscape and its capacity to advance OL, we conducted a content analysis, defined as a "systematic and objective quantitative analysis" (Neuendorf, 2017, p. 1), of available ocean XR experiences. This type of analysis is typically used to examine messaging in text, drawings, video, or games (Stemler, 2000). In this study, we extend this methodology to include publicly available AR, MR, and VR experiences.

3.1. Search for Ocean XR Content

Queries were prompted between January and February 2023 across commercially available online marketplaces (see Supplementary File, Table A) to compile a list of AR, MR, and VR experiences related to the ocean. The search criteria consisted of any combination of the following terms: "ocean," "marine," "sea," "water," and "reef." The researchers relied on industry and academic networks to retrieve ocean XR experiences that were not listed on the public marketplaces but were publicly available through various channels (e.g., museum exhibits).

A total of 109 ocean XR experiences were identified, and 94 were included in our analysis (Figure 3). One duplicate was removed, and 14 others were removed for any one of three reasons: (1) they were standalone 360-degree videos (3 DoF), and therefore outside the scope of this work because they do not feature on the XR spectrum of virtuality, thus meriting their own investigations; (2) they did not integrate the ocean into aspects of the gameplay and/or narrative, for example, XR experiences that only featured the ocean as scenery and 3D asset viewers with AR capabilities were removed; and (3) they were not downloadable or functional.

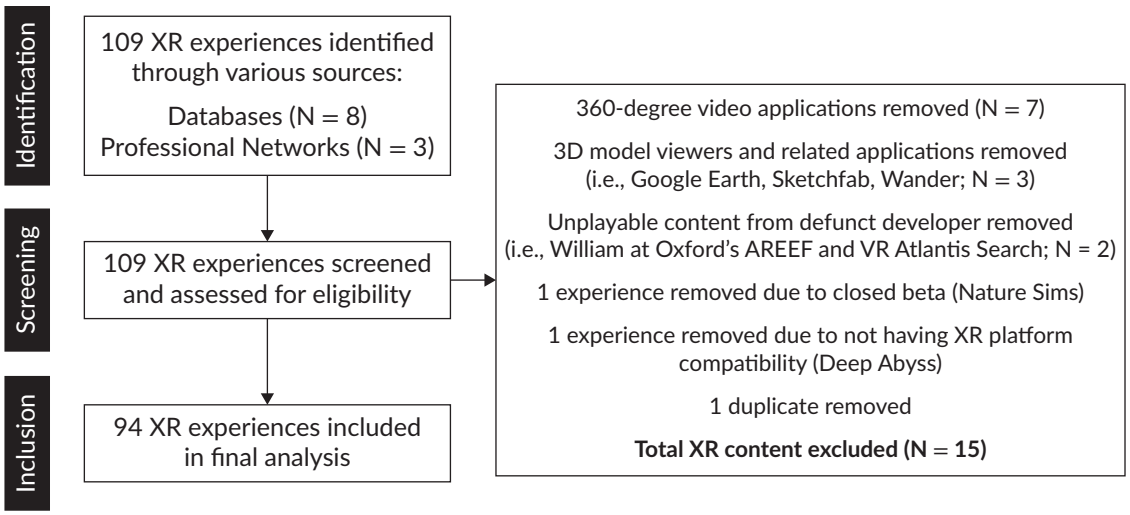

Figure 3. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flowchart.

3.2. Codebook

A codebook gathering the variables and their respective codes was developed based on existing theories and concepts relevant to the fields of XR and OL. Six coders iteratively designed the codebook (Bernard & Ryan, 2010). The final codebook included 23 variables divided into three sub-categories: product information, design features, and OL alignment.

3.2.1. Product Information

To understand the ocean XR landscape, eight variables were identified to describe the structural and logistical characteristics of ocean XR content:

1. Release year: The year the XR experience was released. If the same experience was launched multiple times on different platforms or for different hardware, the earliest year was used.

2. XR modality: The XR modality used to access the content, i.e., AR, MR, or VR (Figure 4).

3. Price: The price (in USD) of the XR experience, as listed during data collection.

4. In-app purchases: Whether the experience allows users to spend money for in-game content.

5. Responsible entity: The entity responsible for the development and/or distribution of the ocean XR experience based on the available public-facing information (e.g., marketplaces, product website, etc.). The options were "NGO," "government agency," "company," "individual creator," and "multiple partners" when more than one of the previous options applied. Along with coding for the kind of entity listed, we listed the name of the developer.

6. Countries: The number of countries (and their names) involved in the creation of the XR experience.

7. Languages: The number and names of languages supported by the XR experience; language support could range from captions to narration.

8. Hardware: All hardware compatible with the XR experience.

Figure 4. Examples of ocean XR content included in the analyses: (a) AR Reef (AR), (b) Undersea (MR), and (c) The Blu (VR).

3.2.2. Ocean XR Features

To uncover how XR features contribute to ocean XR content, we coded for the absence (a) or presence (b) of the following variables:

- Multiplayer functionality: allows cooperative play.
- Six DoF: enables user movements across all 6 spatial axes (roll, pitch, yaw, surge, sway, and heave).
- Wildlife presence: contains visual representations of living organisms. We also listed which organisms appeared.
- Wildlife interactions: user actions (e.g., button presses) elicit responses from depicted wildlife. A third code, "N/A," was used when the ocean XR content did not depict any wildlife.
- Environmental interactions: allows users to control or manipulate digital objects.
- Embodiment: allows the user to embody, or be visually represented by, an avatar by featuring part of the user's body in real-time.
- STEM role: allows users to assume the role, either via narrative and/or gameplay, of a STEM professional or technical expert.
- Environmental threat depiction: features any human-caused environmental threat.

3.2.3. OLPs in Ocean XR Experiences

We also coded for the absence (a) or presence (b) of alignment between each ocean XR experience and each of the OLPs (Figure 1). Figure 5 illustrates how two ocean XR experiences align with OLPs. The Ocean Week Canada AR experience features OLP5 ("the ocean supports a great diversity of life and ecosystems") by showcasing animated digital models of various species of whales and dolphins. The Stanford Ocean Acidification Experience in VR addresses OLP3 ("the ocean is a major influence on weather and climate") by describing how the ocean absorbs a significant portion of the carbon dioxide added to the atmosphere, and OLP6 ("the ocean and humans are inextricably connected") by explaining how human activities are responsible for changing the pH of the ocean.

Figure 5. Examples of the alignment of XR experiences and OLPs. Note: Specific OLPs are overlaid on a screengrab of each experience.

3.3. Coding Ocean XR Experiences

Six coders conducted the content analysis. For each XR experience, guided by the 23 variables of the codebook, they (a) found product information, (b) examined the experiences' content, and (c) assessed alignment with OLPs. Coders played each assigned XR simulation, either in its entirety or for 30 minutes, which represents an average session time for VR (Steam, 2021) and the battery life for commercially available AR headsets (BBC News, 2021), whichever criterion was met first. To assess inter-rater reliability, coders reviewed, discussed, and clarified the codebook before independently coding 10 XR experiences. We used Gwet's AC1 statistic for its suitability with binary coding schemes and uneven distribution responses (Ohyama, 2021), as most XR experiences were coded as not having OLPs meaningfully integrated. Gwet's AC1 is also a strong alternative to other reliability measures (e.g., Kappa; Jimenez & Zepeda, 2020). When reliability was below a moderate level, researchers discussed the codes again, clarified the interpretation of the variables, modified them, and independently re-analyzed a new set of 10 experiences. Three iterations were needed. All AC1 values achieved a fair (> 0.21), moderate (> 0.41), or high agreement (> 0.61), ranging from 0.31 to 0.97 (see Walsh et al., 2022). The *p*-values for each code were significant (all p's < 0.001).

4. Results

4.1. The Landscape of Ocean XR Content

The publication dates of the 94 XR experiences analyzed ranged from 2014 to April 2023, when data collection stopped (Figure 6). The dataset consisted of 26 experiences in AR, 5 in MR, and 63 in VR.

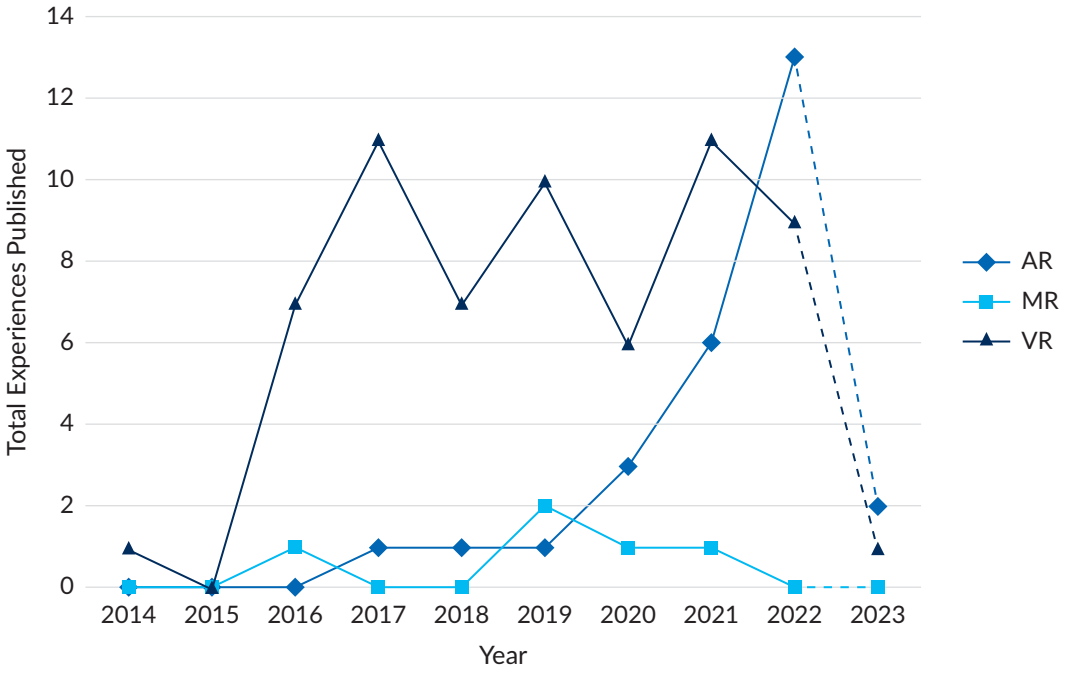

Figure 6. Number of ocean XR experiences, by XR modality, published by year, and accessible at the time of data collection. Notes: The dataset does not present the complete amount of ocean XR content published for 2023, thus, the apparent drop (dotted line) between 2022 and 2023; the dataset only includes ocean XR content available at the time of this study.

The cost of the ocean XR experiences varied greatly. All AR experiences were free. Four MR experiences were free while one cost $50. Roughly a fourth (26.9%) of the VR experiences were for purchase (M = $7.89, SD = 0.99).

Companies are the primary type of entity responsible. They created about two-thirds of the ocean XR content (Figure 7). Fifteen experiences are from individual creators, and 13 are from multiple partners. NGOs are responsible for four ocean XR experiences, and government entities created two.

The ocean XR content came from 26 countries, with 43.6% from the US exclusively, 6.3% from the UK exclusively, 5.3% from Australia exclusively, and the remaining 44.8% from 21 other mainly high-income countries. Only five ocean XR experiences were created at least in part by middle-income countries (World Bank, n.d.). None of the 94 ocean XR experiences were produced by low-income countries. Almost 79% of the ocean XR content is exclusively available in English. French is the second most common language (12.7%), followed by German (10.6%) and Spanish (9.5%). About a quarter (22.3%) of all experiences have more than one language. Most of the AR content is available on smartphones and tablets (iOS or Android),

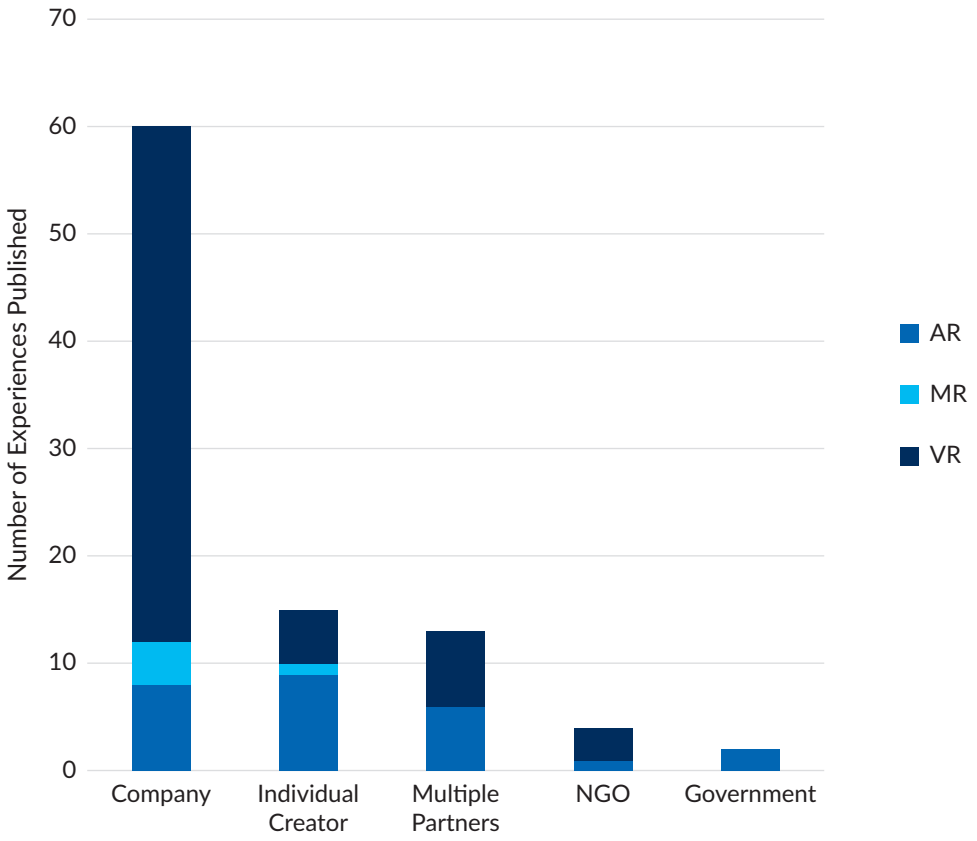

Figure 7. Entities responsible for the development of the ocean XR content by XR modality.

four MR experiences were produced for the Magic Leap 1 HMD, one MR experience was developed for Microsoft's HoloLens, and the ocean VR content is compatible with most HTC and Meta HMDs.

4.2. Ocean XR Features

Analysis of XR experiences yielded insight into the presence of key features according to modality (Table 1).

Table 1. Number (and percentage) of XR experiences with specific features according to modality.

Design features	AR experiences	MR experiences	VR experiences	Total
Multiplayer	0	0	8 (12.70%)	8 (9%)
6 DoF	17 (65.40%)	5 (100%)	59 (93.70%)	81 (8.006%)
Wildlife presence	20 (76.90%)	2 (40%)	52 (82.50%)	74 (79%)
Wildlife interactions	6 (23.10%)	1 (20%)	33 (52.38%)	40 (42.55%)
Environmental interactions	12 (46.20%)	4 (80%)	52 (82.50%)	68 (72%)
Body representation	10 (38.50%)	0	36 (57.10%)	46 (49%)
STEM role	1 (3.80%)	0	27 (42.90%)	28 (30%)
Environmental threat	17 (65.40%)	3 (60%)	25 (39.70%)	45 (48%)

Wildlife depicted in the ocean XR experiences represents a wide range of marine species. Marine invertebrates and fishes are represented equally, with both present in 57% of all experiences. Marine mammals are present in

27 experiences, with whales being the most common, representing 22 of the 40 marine mammals that appear across all content. Of the 93 appearances of fish across all experiences, 24 are sharks. Reptiles, mainly sea turtles, appear in 20 experiences. Plants and protists, including seagrass, mangroves, and algae, were featured in 10 experiences. Birds, including penguins and seagulls, are featured in four experiences. Corals are the most frequently featured invertebrate, present in 30 experiences. Of all 89 appearances of invertebrates, 48 are cnidarians (e.g., corals and jellyfish), 18 are mollusks (e.g., octopuses and squids), and 17 are echinoderms (e.g., sea stars and urchins). Five of the eight marine invertebrate phyla were represented, while the three worm phyla—platyhelminthes, nematodes, and annelids—were not represented. Six XR experiences presented mythical or prehistoric animals (categorized as "other").

4.3. OLPs in Ocean XR Content

Of the 94 experiences, 84 address at least one OLP through narration or gameplay (see Supplementary File, Table B, for percentages of XR experiences addressing between zero and seven OLPs). Table 2 shows how frequently each OLP is addressed in each XR modality. Most AR experiences (80.80%) touch upon OLP6. All the OLPs are included among the 63 VR experiences. The least frequently addressed in VR is OLP2, with only one experience covering it. The most common in VR is OLP5, which is addressed in 66.60% of the VR content. When looking across all XR experiences, OLP6 is most frequently addressed, while OLP4 is the least (see Supplementary File, Table B, for percentages of XR experiences addressing a specific number of OLPs).

Table 2. Number (and percentage) of XR experiences per modality, addressing each OLP.

OLPs	AR experiences	MR experiences	VR experiences	Total
1: Earth has one big ocean with many features	0	3 (60%)	18 (28.60%)	22 (23.40%)
2: The ocean and life in the ocean shape the features of Earth	0	2 (40%)	1 (11.10%)	9 (9.60%)
3: The ocean is a major influence on weather and climate	3 (11.50%)	3 (60%)	8 (12.70%)	14 (14.90%)
4: The ocean makes Earth habitable	2 (7.70%)	3 (60%)	2 (3.20%)	7 (7.40%)
5: The ocean supports a great diversity of life and ecosystems	14 (53.80%)	2 (40%)	42 (66.60%)	58 (61.70%)
6: The ocean and humans are inextricably interconnected	21 (80.80%)	3 (60%)	37 (58.70%)	61 (64.90%)
7: The ocean is largely unexplored	0	0	27 (42.90%)	28 (28.70%)

4.4. OLPs and XR Features

An exploratory correlation analysis was conducted between the OLPs addressed in each ocean XR experience and XR features. Table 3 presents the correlation between variables with Phi coefficients, given the binary nature of the variables. Several design features are positively associated with specific OLPs. For example, 6 DoF is positively associated with OLP1, wildlife presence and interactions are strongly related to OLP5, body representation and assuming a STEM role are strongly related to OLP7, and the presence of environmental threats is positively related to OLPs 3, 4, and 6.

Table 3. Pearson's *R* correlation coefficient matrix between OLPs and design features.

OLP	Multiplayer	6 DoF	Wildlife presence	Wildlife interaction	Environmental interaction	Embodiment	STEM role	Environmental threat
1	−0.17	0.22*	0.10	0.18	0	0.01	0.19	0.17
2	−0.10	0.13	−0.10	0.09	0.04	−0.03	0.03	0.12
3	−0.02	0.08	−0.15	−0.06	0.06	0.07	0.05	0.20
4	−0.09	0.11	−0.15	−0.16	−0.10	−0.12	−0.10	0.22*
5	0.16	0.13	0.66**	0.41**	0.15	0.11	0.18	0.19
6	−0.02	−0.04	0.16	0.05	0.19	0.10	−0.06	0.62**
7	0.06	0.12	0.27**	0.21*	0.18	0.32**	0.66**	0.10

Notes: * Correlation is significant at the 0.05 level (2-tailed); ** correlation is significant at the 0.01 level (2-tailed).

5. Discussion

This study provides the first overview of the characteristics of ocean XR experiences, their affordances for marine education, and their relationship to essential principles of ocean literacy (OLPs).

5.1. The Landscape of Ocean XR

The results show that ocean XR content is characterized by an emphasis on VR, although ocean AR content has seen steady growth since 2018. This could be explained by a general XR industry trend to bolster AR accessibility and content creation, as game engines used to develop mobile AR are enabling easier creation and distribution (Cappannari & Vitillo, 2022). Additionally, advances in 5G communication networks and continued ubiquity of AR-capable smartphones make AR content increasingly accessible, further incentivizing development (Qiao et al., 2019). Contrasting with VR and AR's dominance, ocean MR has stayed anecdotal. MR hardware manufacturers, such as Magic Leap, have shifted away from consumer-facing content, emphasizing enterprise clients (Robertson, 2020).

For-profit companies were the largest source of ocean XR experiences, followed by individual creators. There was a clear relationship between responsible entities and modality: company-created content was largely made for VR, whereas content from individual creators was primarily made for AR. This finding supports the notion that AR is a more accessible modality both for consumers and creators, while also emphasizing the fact that VR development costs are likely manageable by organizations creating ocean XR content for entertainment and revenue. Most consumer-facing VR content has been designed for entertainment, with the most popular genres of VR being action and adventure (Foxman et al., 2021). While the marketplace continues to evolve rapidly, this observation reflects the state of the field as of 2021. While costs varied among ocean XR (with all AR being free), only one of the 94 experiences listed (a VR experience) had in-app purchases. This is consistent with the broader field: in-app purchases are only available in 1% of all commercially available VR experiences (Foxman et al., 2021).

Only 9% percent of all ocean XR experiences analyzed offer multiplayer functionality (one AR and seven VR). Consumers are generally apprehensive about investing in expensive VR headsets for social or multiplayer experiences due to concerns that insufficient adoption by other users will render the device and its multiplayer

potential useless (Sykownik et al., 2023). Similarly, integrating multiplayer functionality into XR games comes with the added expense of servers to host multiple users (Amazon, n.d.).

The majority (86%) of ocean XR experiences provide 6 DoF, enabling users to freely roam in their real space, achieving multiple perspectives of digital 3D assets. The ocean XR dataset does not include 360° videos, therefore limiting representation of 3 DoF content in this study. Though this exclusion criterion biases the results towards 6 DoF content, analyzing thousands of available 360° ocean videos was outside the scope of this study.

English is the dominant language, and most of the ocean XR content originated from the US, the UK, Australia, and other high-income countries. This, and the finding that no ocean XR experiences were created in low-income countries, is in line with knowledge that development costs are barriers to creation. A similar bias was highlighted by Shellock et al. (2024) in their systematic mapping of research in OL. They revealed that most research has been conducted by high-income countries (they use the term "global minority"). Future work could investigate whether ocean XR created in high-income countries features marine ecosystems—or targets users—from low-income countries, particularly island nations where the effects of ocean degradation and climate change are disproportionately felt (Intergovernmental Panel on Climate Change, 2022). The biases in ocean XR content creation reflects the ongoing concerns surrounding "parachuting" or "colonial science" in marine research and conservation whereby scientists and NGOs from high-income countries conduct research or deploy programs abroad that "fail to invest in, fully partner with, or recognize local governance, capacity, expertise, and social structures" (de Vos & Schwartz, 2022, p. 1). Therefore, funders and ocean XR creators who seek to contribute to OL and/or marine conservation would benefit from seeking out and supporting partners and XR creators from marginalized communities or based in regions most impacted by ocean issues. The target audience and location of ocean XR content depend on the expected outcomes. An ocean XR experience that portrays the effects of climate change on ocean ecosystems, for instance, may be better aimed at users, industry leaders, and policy makers in the highest-emitting countries like the US and China. Additionally, only 9 of the 94 XR experiences analyzed involve multiple countries, with 13 ocean XR experiences created by multiple partners, further pointing to an opportunity for transdisciplinary collaboration in ocean XR content creation. The potential cultural and international diversity of individual XR creators based in the countries of highest output should not be discounted, as many XR developers in the US, for instance, have emigrated from other countries. Immigrants make up nearly half (45%) of the workforce in Silicon Valley, for example (National Immigration Forum, 2017).

5.2. The Intersection of Ocean XR and OL

A core benefit of ocean XR is how it enables mediated interactions with virtual representations of marine environments and wildlife. While interaction with features in the digital environment (e.g., driving a submarine) was prominent across experiences (72%), interaction with living organisms (e.g., tapping to learn names and lifecycles) was relatively low (42%). This may be due to the costs and technical expertise needed to program human–wildlife interactions and simulate animal behaviors (Zotos et al., 2022).

The majority of ocean XR experiences featured wildlife. Marine mammals like whales and dolphins and seals and sea lions were featured in just under a third of all content. Such charismatic megafauna is well-represented in popular media and is associated with shifts in public perception towards conservation and eco-tourism

(Walpole & Leader-Williams, 2002). The presence of megafauna in ocean XR content might play a similar role in marine education. More experiences featured invertebrates (61%) than marine mammals (29%). This could be because reef-building corals and other benthic invertebrates like sea stars can be conveyed as background and integrated easily into digital settings as 3D assets, whereas animals that swim need to be animated in the experience. Sharks were the most common type of fish across all XR experiences, which is consistent with the prevalence of sharks in popular media (Panoch & Pearson, 2017).

Interaction with real and digital nature has the potential to promote pro-environmental attitudes and behaviors (Hinds & Sparks, 2008); however, our findings show that ocean XR content seldom leverages this affordance. Raja (2023) warns against reducing nature to a backdrop or stage solely for entertainment purposes, a risk illustrated by the limited number of ocean XR experiences that allow interaction with the digital ocean and its inhabitants (note that, in real life, some interactions with marine life, such as grabbing or petting, can be harmful to wildlife, dangerous to humans, and counterproductive to ocean education).

The results show significant correlations between OLPs addressed in ocean XR content and the features of the ocean XR experience itself. OLP7 ("the ocean is largely unexplored") significantly correlates with two features in the ocean XR experiences: embodiment and STEM role. Since OLP7 is focused on exploration, this correlation is driven by the user's ability to step into the role of STEM and technical professionals, for instance, a marine scientist piloting a submersible. While embodiment is associated with OLP7, other principles also benefit from user embodiment. Previous work has shown that embodying a virtual scientist in VR can improve youth engagement with science (Pimentel & Kalyanaraman, 2022). Agency and self-efficacy seem positively correlated when learning in VR (Makransky & Petersen, 2021). Self-efficacy seems to be a driver behind climate change adaptive behavior (van Valkengoed & Steg, 2019), and studies show that embodying a scuba diver can increase ocean acidification knowledge (Markowitz et al., 2018). However, it is worth noting that despite the ubiquity of avatar features in gaming and education, less than half of the ocean XR experiences enabled users to embody a virtual character. Even fewer (30%) placed users in specific STEM or technical roles. This disparity is important considering character embodiment influences information processing in XR (Sakuma et al., 2023), and users' perceptions of their roles in virtual contexts can influence their behaviors (Slater et al., 2010).

OLP7 also correlates with the presence of wildlife and their interactivity. Exploring the ocean, the topic of OLP7, includes encountering and interacting with underwater life. OLP6 ("the ocean and humans are inextricably interconnected") is significantly correlated to the depiction of human-based environmental threats in the ocean XR experiences. As most human impact on the ocean is deleterious, the topic of environmental threats is related to the human–ocean connection. OLP5 ("the ocean supports a great diversity of life and ecosystems") is correlated with the presence of and interaction with wildlife. The presence of different types of wildlife in an experience inherently addresses biodiversity and creates an opportunity for interactivity. Some significant correlations were found for OLP1 ("Earth has one big ocean with many features") and DoF. OLP4 ("the ocean makes Earth habitable") correlates to the presence of an environmental threat. The mechanisms behind these correlations are unknown and further exploration into the intersection of OLPs and XR design features is needed.

Human societies have a growing need to restore ocean health through sustainable behaviors and policies. All available communication and educational tools should be investigated to maximize their contribution to

this endeavor. The specific affordances of XR could play a significant role in increasing OL. While the number of available ocean XR experiences and the research about their impact is currently limited, interest from the XR community is growing. We call for this community to further investigate XR for OL. A new theoretical framework could identify how specific XR features facilitate the process of learning specific OLPs. Research shows that embodiment heightens the sense of being there (spatial presence) and being with (social presence; Wirth et al., 2007). The feeling of embodiment is influenced by character roles and by having a salient threat affecting the user in the digital environment (Fribourg et al., 2021). Because embodiment facilitates the user seeing causal relationships between themselves and the virtual context, it could be proposed as contributing to learning about OLP 6 ("the ocean and humans are inextricably interconnected"), which emphasizes codependency between the user and the environment (i.e., the user's survival in the simulated environment can be linked to how the ocean and humans are inextricably interconnected).

Ocean XR creators who seek to enhance OL should avoid superficially relating to OLPs and instead use them to their full potential, for instance by providing details about marine biodiversity when incorporating OLP5, e.g., using interactive imagery, narration, or text that describes and illustrates a green sea turtle's geographical range, its endangered status, or reproductive patterns rather than only featuring a visual representation of a sea turtle. While the public's knowledge about the ocean is important, it is currently insufficient—as evidenced by low OL rates worldwide (Guest et al., 2015). Solely providing information is not enough to trigger behavioral or attitudinal change (Kollmuss & Agyeman, 2002). Ocean XR experiences should therefore go beyond providing facts to offering vicarious nature experience (Kellert, 2002) to enhance connection to marine environments. Such "nature connectedness," defined as the emotional closeness to nature and the feeling of being an integral part of it (Hinds & Sparks, 2008), is crucial to science and environmental learning, and restoring ocean health. Firsthand experience of an environmental issue is more impactful than secondhand information (Spence et al., 2011), as it influences how individuals learn about and perceive risks. Researchers have found a positive correlation between experiencing environmental issues and increased environmental risk perception, pro-environmental attitudes, and behavior (Lang & Ryder, 2016). XR creators have the opportunity to design new ways to meaningfully experience the natural world, especially places that are hard or impossible to visit in person.

5.3. Limitations of the Study

This study has several limitations. The 94 experiences analyzed are unlikely to represent all ocean XR content ever published, as some experiences are no longer available. Accessibility levels are always changing. For instance, LensList, an online database of AR content that was free when we collected the material, is now behind a paywall. Modalities across the spectrum of virtuality were not evenly represented. Most of the dataset consisted of AR and VR content, as we found and analyzed very few ocean MR experiences, making it difficult to identify patterns and draw conclusions about that modality. The 30-minute time limit for each individual coder's playtime may also have affected the results. Though most of the experiences were completed well within that time, some longer experiences may have specific features or OLPs in later stages that the coders missed. The analysis does not measure the extent to which a specific XR experience addresses the content of OLPs. An XR experience briefly touching upon marine diversity by showing various species will be coded similarly to an experience that provides in-depth educational content about the same marine life. While both experiences would align with OLP5 ("the ocean supports a great diversity of life and ecosystems"), the latter has a greater potential to enhance the user's understanding that marine biodiversity

is significantly greater than terrestrial biodiversity. We also did not investigate where and how these XR experiences are integrated into formal or informal curricula, if at all. We expect that the effectiveness of ocean XR is enhanced when scaffolded by established teaching methodologies, and we encourage further research into this topic. An additional limitation in this study is that, due to resource limitations, we did not code for the 45 fundamental concepts within the OLPs. Future studies that address these detailed concepts may reveal more nuances in how OLPs are applied in ocean XR. Finally, we coded for embodiment specific to STEM professionals because a large body of research has investigated the impact of embodiment where users specifically take on the role of a STEM professional for learning. We acknowledge that this creates a bias that ignores other identities and expertise relevant in marine education and conservation, for instance, traditional Indigenous knowledge of sustenance fishing. In future work, we encourage researchers to investigate a broader range of cultural representations that are meaningful for OL.

6. Conclusion

This study constitutes the first attempt to visualize the landscape of ocean XR content and assess its potential for improving marine environmental education and promoting OL. Based on this work, we offer three recommendations for future ocean XR content. First, we suggest applying key affordances of XR to offer more meaningful virtual ocean experiences. Second, we encourage more collaborative ocean XR content across disciplines and countries, including equitable partnerships with creators from underrepresented communities. Finally, we suggest conducting further research to examine the causal relationship between key features and learning outcomes, to have a clearer picture of the extent to which ocean XR content can support OL.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The list of the ocean XR experiences, along with the coding, can be found in the OSF project at https://osf.io/8u2xq

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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