frontiers | Frontiers in Marine Science

TYPE Systematic Review
PUBLISHED 28 August 2025
DOI 10.3389/fmars.2025.1648508



OPEN ACCESS

EDITED BY
Guangnian Xiao,
Shanghai Maritime University, China

REVIEWED BY
Panayota (Yolanda) Koulouri,
Hellenic Centre for Marine Research (HCMR), Greece
Ana Cristina Costa,
University of the Azores, Portugal

*CORRESPONDENCE
Mariana Almeida
mariana@ua.pt
Helena Vieira
helena.vieira@ua.pt

RECEIVED 17 June 2025
ACCEPTED 30 July 2025
PUBLISHED 28 August 2025

CITATION
Almeida M, Laranjeiro D, Costa R, Lillebø AI and Vieira H (2025) Blue economy concepts are lagging behind in ocean literacy. *Front. Mar. Sci.* 12:1648508. doi: 10.3389/fmars.2025.1648508



# Blue economy concepts are lagging behind in ocean literacy

Mariana Almeida[1*], Dionísia Laranjeiro[2], Raquel Costa[3], Ana I. Lillebø[4] and Helena Vieira[1*]

[1]CESAM – Centre for Environmental and Marine Studies and Department of Environment and Planning, Universidade de Aveiro, Aveiro, Portugal, [2]CIDTFF – Research Centre on Didactics and Technology in the Education of Trainers, Department of Education and Psychology, University of Aveiro, Aveiro, Portugal, [3]UIDEF-Research and Development Unit in Education and Training, Instituto de Educação, Universidade de Lisboa, Lisboa, Portugal, [4]ECOMARE, CESAM – Centre for Environmental and Marine Studies, Department of Biology, Universidade de Aveiro, Aveiro, Portugal

**Introduction:** Ocean Literacy has been recognized as crucial in promoting a Sustainable Blue Economy.

**Methods:** This work carried out a literature review to understand how Ocean literacy and Blue Economy concepts are being associated. In particular, it examines what Key concepts related to Blue Economy like technology, circularity, economics or careers are being addressed within Ocean Literacy. Additionally, to capture the work developed outside the academic research domain, the Portuguese (PT) Blue School Network was selected as a source for identifying educational activities related to the Blue Economy, as it brings together initiatives provided by a diverse range of stakeholders.

**Results:** Our analysis revealed a limited, though growing, body of scientific work connecting Ocean Literacy and Blue Economy (25 publications), prominently from Europe, possibly a reflection of the European Union's policy frameworks on the blue economic growth. Blue Economy is the most frequent economic topic, followed by specific sectors within Blue Economy, including aquaculture, fisheries, shipbuilding and offshore renewables. The Circular Economy concept arises in the context of plastic pollution whereas Environmental Economy concepts are associated with cultural values and restoration of marine ecosystems. The analysis of the Blue School PT program revealed that around 20% of the activities offered consider Blue Economy related topics. Within these topics, careers is the most covered issue, followed by circular economy and aquaculture. Fishing, fish consumption, biotechnology, economy and research are other issues covered. Emergent Blue Economy sectors, such as energy, robotics, and tourism, received less attention.

**Discussion:** This review underscores the need for greater integration of economic concepts within Ocean Literacy initiatives and illustrates the variety of economic issues that can be addressed to further promote the sustainable use of ocean resources. It also highlights that expanding research and educational efforts to the economic and societal dimensions of the ocean are crucial for achieving comprehensive Ocean Literacy, more aligned with the actual holistic concept of Ocean Literacy.

KEYWORDS

**circular economy, marine policy, marine education, maritime industry, sustainability, environmental economics, blue schools**

# 1 Introduction

The ocean plays crucial roles in climate regulation, sustaining a vast biodiversity and providing resources and many benefits that contribute to human welfare (Costanza et al., 1997). Despite its universal significance, it was only in the last decade that initiatives have globally increased to promote society understanding of marine ecosystems and how human interactions with the ocean exert multiple anthropogenic pressures. This understanding, as proclaimed by the UN Decade of Ocean Science for Sustainable Development (2021-2030) (the "Ocean Decade"), is crucial to enable responsible behaviours, support informed decision-making, and foster global cooperation and engagement in ocean conservation, management and restoration efforts – aimed at restoring degraded ecosystems to reverse biodiversity loss and address climate change (European Parliament and the Council of the European Union, 2024; UNESCO-IOC, 2021). In particular, it aligns with the Sustainable Development Goal 14[1] of the Agenda 2030, specifically Target 14.C, which calls for the conservation and sustainable use of oceans and their resources to be enhanced through the implementation of international law, as set out in the United Nations Convention on the Law of the Sea (UNCLOS), agreed to in 1982 and entered into force in 1994. This provides a legal framework for ocean governance, a commitment reaffirmed in The Future We Want (par. 158), in 2012[2], the outcome document from the United Nations Conference on Sustainable Development.

Numerous, established and emerging, economic activities depend on the ocean, yet they pose significant economic and societal challenges. It is, therefore, crucial not only to promote technological advancements and create regulatory frameworks but also to equip stakeholders such as policy-makers, authorities and citizens with the tools needed for sustainable economic practices (Hemer et al., 2018). The growing economic importance of the oceans has been widely recognised in international reports. The OECD (Organization for Economic co-operation and Development), for example, has emphasised the significant potential of ocean-based industries to contribute to global economic growth. The organisation estimates that, by 2030, the ocean economy could double its contribution to global value added and employment (OECD, 2016). More recent projections, extending to 2050, emphasise the need for integrated policy approaches to ensure this growth remains sustainable and inclusive (OECD, 2025). Global events such as the World Ocean Summit (https://www.unesco.org/en/articles/12th-annual-world-ocean-summit-expo) and initiatives like the World Bank's PROBLUE programme (https://www.worldbank.org/en/programs/problue) reinforce the urgent need to align ocean-related economic development with environmental sustainability and social equity. These perspectives emphasise the importance of fostering ocean literacy, particularly in economic terms, to empower stakeholders, such as policymakers, institutions and citizens to make informed decisions that support the sustainable use of marine resources. Ocean Literacy refers to people´s understanding of the ocean's influence on them and their influence on the ocean. It includes knowing fundamental concepts about the ocean, being able to communicate them in a meaningful way, and making informed decisions about the ocean and its resources (Cava et al., 2005). Furthermore, Ocean Literacy serves as a framework for exploring ocean issues through diverse knowledge disciplines, recognizing local, regional and global perspectives, and applying decision-making processes to address complex challenges that affect individual, community, and global well-being (Santoro et al., 2017). Ocean Literacy plays a role in addressing these challenges through different actions, as demonstrated by its integration into several international and policy frameworks such as the Ocean Decade (UNESCO-IOC, 2021), the Venice Declaration for Ocean Literacy in Action (UNESCO, 2024) and the Ocean Decade Vision 2030 White Paper Challenge 10 - Restoring Society's Relationship with the Ocean (Glithero et al., 2024). Recently, Ocean Literacy has evolved to a more holistic approach including multiple dimensions, such as knowledge, communication, behaviour, awareness, attitudes, activism, emotional connection, access and experience, adaptive capacity, and trust and transparency (McKinley et al., 2023). These dimensions reflect a broader and deeper understanding of the ocean, emphasizing not just knowledge but also engagement and responsibility in relation to ocean sustainability.

Recent Ocean Literacy literature revisions have shown that scientific knowledge of the ocean, especially in an educational context, has been the unique dimension explored and evaluated (Cavas et al., 2023; Paredes-Coral et al., 2021; Shellock et al., 2024). This approach is valid to promote, engage and increase the society's knowledge on the ocean ecosystem and its biological, chemical and physical functions and characteristics., However, it poses a challenge in fostering a holistic understanding of the social, cultural, and economic dimensions of human-ocean interactions. This perspective is essential for promoting sustainable practices in the related different economic sectors as well as addressing the complex challenges of ocean management and resource use (McKinley et al., 2023).

According to the European Commission, "the blue economy encompasses all sectoral and cross-sectoral economic activities related to the oceans, seas and coasts". "It includes emerging economic sectors, but also economic values based on natural capital and non-market goods and services through the conservation of marine habitats and ecosystem services" (European Commission, 2021). Blue Economy encompasses a diverse range of economic sectors such as fisheries, aquaculture, maritime transport, and tourism, as well as expanding and emerging fields, like biotechnology and ocean renewable energies (European Commission, 2024). Sustainable Blue Economy is closely tied to concepts like circular economy, bioeconomy, and environmental economics, which together ensure a comprehensive approach to address economic growth with environmentally responsible action (Barañano et al., 2021). By aligning the Blue Economy with circular economy principles, resource efficiency is maximized, and waste is minimized,

1 https://sdgs.un.org/goals/goal14#targets_and_indicators.

2 https://sustainabledevelopment.un.org/futurewewant.html.

reducing the environmental impact of ocean-based activities (Bellei et al., 2023). The Blue Economy is also closely linked to the Bioeconomy, as it focuses on the sustainable harvesting and processing of biological resources, including those from the ocean. This approach aims to produce novel bio-based products such as food, materials and energy, often with the incorporation of biotechnology and biomanufacturing, to enhance the efficiency and sustainability of marine-based production (Barañano et al., 2021). Both these concepts, bioeconomy and circular economy are often aligned; for example, fish by-products can be used in animal feed or as a source of compounds for pharmaceutics (Vieira et al., 2023). Environmental economics play a crucial role by providing a framework for valuing marine natural capital and incorporating the costs of environmental impact into decision-making (Barañano et al., 2021). For instance, the design of Marine Protected Areas (MPAs) can include the valuation of ecosystem services of a given area and examines the costs and benefits of different environmental practices. This analysis further supports sustainable development policies and strategies, ensuring that MPAs contribute to both environmental sustainability and economic well-being (Barbier, 2012; Davis et al., 2019). The integration of these frameworks can help address the interconnected challenges of ocean resource management, economic development, and conservation (Figure 1).

These concepts foster interdisciplinary collaboration in ocean-related arenas and across several disciplines, such as marine science, education, social sciences, and economics.

Recognizing the potential of Ocean Literacy to drive a societal paradigm shift towards sustainable economic practices, this research aims to 1) characterize the academic landscape by examining the integration of economic concepts - particularly those related to the Blue Economy - within the Ocean Literacy framework; and 2) to evaluate the implementation of Blue Economy concepts in educational practice. This second objective stems from recent literature data, which indicates that Ocean Literacy studies mainly concentrate on educational contexts, with limited attention to their integration into broader societal frameworks like the Blue Economy.

For the first objective, a systematic review of bibliographic databases was conducted to: a) identify key characteristics of Ocean Literacy and Blue Economy research, including growth trends, leading countries, and publication outlets; and b) explore how studies linking Ocean Literacy and the Blue Economy are structured across thematic areas such as the circular economy, environmental economics, and socio-economic contexts, as well as how these topics are addressed in Ocean Literacy research.

To complement the systematic review and capture how Ocean Literacy is implemented, this study also examined the Portuguese Blue School programme (Escola Azul, official website: https://escolaazul.pt). The programme was chosen due to its longevity and wide school adherence, extensive online information, collaborations and partnerships, including with governmental agencies, NGOs and private sector. By analysing the types of activities and resources offered by diverse stakeholders in this initiative, the study gains insight into how Blue Economy principles are translated into concrete educational actions.

Together, the systematic literature review and the analysis of the Escola Azul programme provide a comprehensive picture of both theoretical and practical approaches to integrating Blue Economy principles into Ocean Literacy.

. Both approaches supported the actionable recommendations put forward for researchers, educators, and policymakers to strengthen the connection between Ocean Literacy and the Blue Economy to gain a more comprehensive understanding of the holistic relationship between the economy, societal and cultural aspects and ocean sustainability.

# 2 Material and methods

## 2.1 Literature search and analysis

A literature search was conducted in Scopus (https://www.scopus.com/), Web of Science (https://www.webofscience.com/) and Open Alex (https://openalex.org/) databases to analyse the available scientific information related to publications addressing Ocean Literacy and Blue Economy, based on PRISMA guidelines (Page et al., 2021).

To analyse Ocean Literacy as a concept a search was conducted in June 2024 using the keywords “ocean”, “literacy” “literate” and “economy”. These terms were applied in the title, abstract and keywords without restricting the publication year, to capture overall

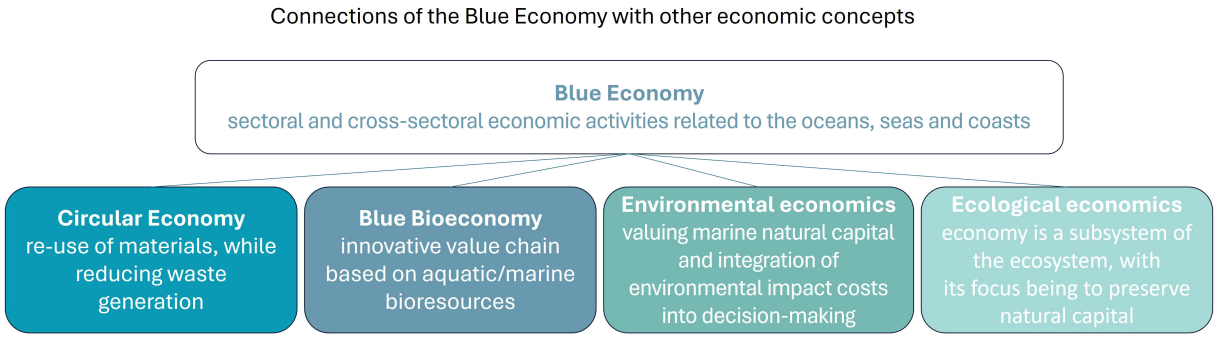


FIGURE 1
Connections of the Blue Economy with other economic concepts.

TABLE 1 Keywords combinations and documents retrieved.

| Query | Documents retrieved |
|---|---|
| [("ocean literacy") OR ("ocean literate") OR (ocean AND literacy)] AND (economy*) | Scopus: 84<br>WoS: 74 |
| [(ocean literacy) OR ("ocean literacy") OR ("ocean literate") OR (ocean AND literacy)] AND (economy OR economic OR economies) | OpenAlex: 170 |

publication trends in these topics (Table 1). The use of the keyword "economy" allowed the retrieval of documents related to Blue Economy and associated topics, such as circular economy and environmental economy (Barañano et al., 2021).

The total search yielded 328 publications. Publications retrieved were merged and duplicates were removed. Next, each publication was screened based on its title and abstract and only those studies fitting the research's inclusion criteria were extracted (Figure 2). The selected articles were then subjected to a full-text analysis to ensure they met the inclusion criteria, which focused on studies on Ocean Literacy that addressed economic topics. Documents that mentioned "economy" only in the introduction or those focusing solely on economic impacts were excluded. Journal articles, reviews, conference papers and book chapters, written in English, were included and inaccessible articles were excluded from the study. The process resulted in the selection of 25 articles (Figure 2; Supplementary Material S1).

The analysis examined growth indicators, such as the annual number of publications and the countries of origin for these publications, by attributing each publication to its respective author's country. Furthermore, the study examined the journals in which these publications were featured. Subsequentially, specific content of publications was analysed, including: a) methods employed in the study, b) the study type carried out in the publications and c) which economic topics were addressed. The identification of the study type associated with each publication (e.g., whether it was educational material or an engagement activity) was based on the framework established by Shellock et al. (2024). This framework categorizes study types into intervention categories, such as education and learning, engagement and connection, training and development, among others. To identify the economic topics in the publications, each publication was analysed for information linking Ocean Literacy to economic aspects, specifically blue economy, circular economy and environmental economics. Relevant information from the results, discussion, and/or conclusions was extracted, and the publication was assigned to the corresponding economic concept. Within the Blue Economy, publications that addressed the topic broadly were categorized under "Blue Economy," while those focusing on a specific sector were assigned to that sector.

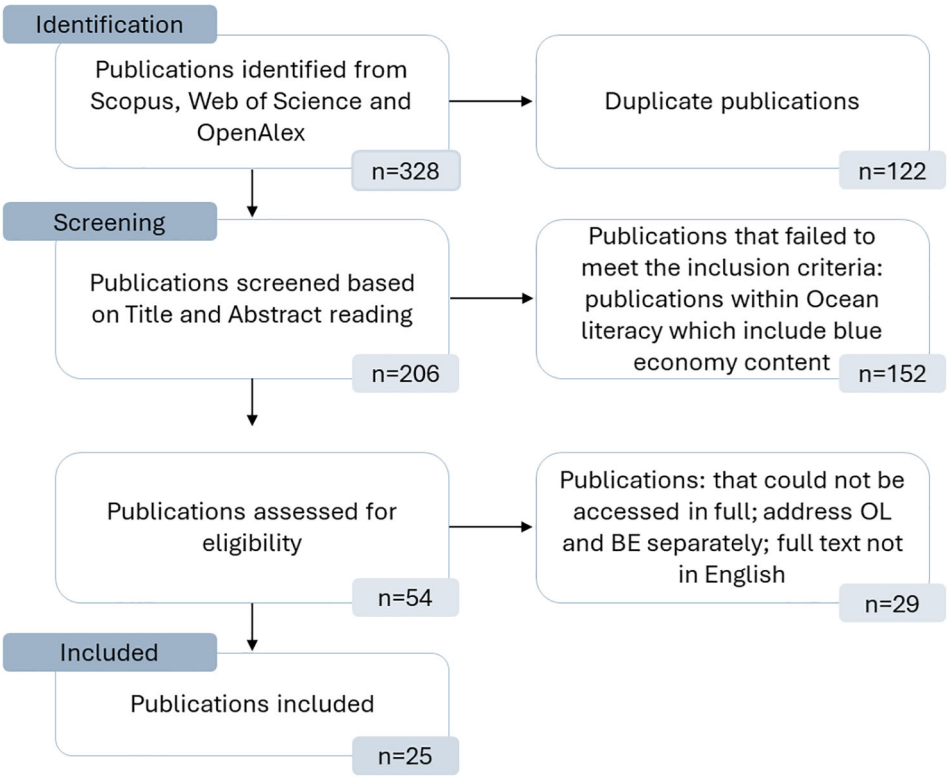


FIGURE 2
PRISMA flow diagram for the systematic review.

### 2.2 Selection and analysis of an educational programme

In addition to the publications 'analysis, the Portuguese pioneer Ocean Literacy educational Blue School PT programme was selected to capture the work developed in Ocean Literacy and Blue Economy in an educational setting, outside the academic research domains. The Portuguese "Blue School" programme, is a national Ocean Literacy educational initiative and one of the first formal Ocean Literacy programmes worldwide (Costa and Faria, 2025). This programme certified schools that explore ocean issues integrated into their curriculum. Furthermore, this concept/model has inspired similar initiatives at the European (EU Blue Schools Network) and Atlantic level (All-Atlantic Blue Schools Network), and recently the Blue School Global Network coordinated by IOC-UNESCO (https://oceanliteracy.unesco.org/projects/blue-schools-global-network). The programme support schools that fulfil the Blue School criteria: a Blue School will explore ocean issues, across different disciplines of knowledge and encourage students of different ages to act, intervene and decide conscientiously, selecting Ocean ambassadors; it interacts with a network of partners, involves the local community and communicates its actions. This initiative creates a community that brings together schools, the private sector, municipalities, NGOs, universities and other organisations connected to the sea, who provide multidisciplinary marine education activities.

The educational offer is divided into activities and resources, developed in collaboration with the network of partners (official website: https://escolaazul.pt). Activities, which are developed for the participating schools, are organized in a structured repository, with functionalities of search and filter by partner, geographical location, level/cycle of education and type. The resources are divided into 7 categories, and each category opens a list of associated resources (e.g. educational videos, documents such as pedagogical guides and interactive materials such as games).

To understand the programme's coverage on ocean-related economy topics, a search of its educational activities was conducted in June 2024. This search involved an assessment of the official website (https://escolaazul.pt), particularly the structured repository where activities are categorized and which can be filtered by various criteria, including partner organizations, geographical location, educational level, and category/type. The categories/types of activities offered by the Blue School programme were analysed to identify those falling under economy-related topics.

Each activity was screened based on its title and description to assess its relevance to economic topics within the Blue Economy and the ones aligned with these criteria were considered for this purpose. Activities that were already explicitly categorized under ocean economy topics, such as those related to maritime careers, were retained under their designated classifications. Other activities classified under broader categories were also reviewed to determine their specific focus. For example, activities within the category "Fisheries," were analysed to distinguish between activities addressing fisheries as an economic sector—such as those discussing fishing industries, trade, or sustainable fisheries management— from those focusing on fisheries in the context of marine biodiversity or ecosystem conservation. In addition, the total number of activities provided by the programme was then assessed, providing a quantitative overview of the proportion of activities specifically addressing economy topics in relation to the overall number of available activities. An analysis of the entities involved in each selected activity was subsequentially conducted, creating a preliminary dataset on the types of entities and collaborations engaged in delivering specific Ocean Literacy thematic content.

Regarding resources, as this area is not catalogued with metadata, and this study does not aim to carry out a content analysis of the resources listed, a general descriptive approach of what is available on the site was chosen, given its usefulness for the Blue School community. The title of the resource, a short description (when available), the organisation/partner providing the resource, the format of the resource and the level of education for which it is intended were used to this end. The presence of words in the title or in the description that could be associated with Blue Economy -related content was also considered.

## 3 Results and discussion

### 3.1 Growing body of Ocean Literacy research focused on Blue Economy

The literature search yielded a diverse body of publications addressing the intersection of Ocean Literacy and the Blue Economy, providing insights into prevailing research trends, thematic focus areas, and gaps in the existing scientific literature. Our study identified a total of 206 potential publications, of which only 25 publications engaged directly with economic topics. This represents a substantial increase from the previously reported number Paredes-Coral et al. (2021) who identified only 8 publications specifically focusing on the Blue Economy. Our results therefore represent a 312% increase in the number of publications addressing both ocean literacy and economic themes, highlighting growing academic interest in the intersection of these areas. Notably, many of the 25 publications were released after that earlier study, which may partly explain the observed increase. The research contributions span different countries, with Portugal leading the count with 3 publications. Other European and non-European countries are less represented (18 in total) (Figure 3A).

When compared to the 181 peer-reviewed Ocean literacy publications synthesized by Shellock et al. (2024), this suggests that approximately 13.8% of the peer-reviewed OL literature addresses economic dimensions, highlighting the relatively limited attention this intersection has received within the broader Ocean Literacy field.

In a similar mode to the bibliometric analysis conducted by Paredes-Coral et al. (2021) on Ocean Literacy, who assess major thematic areas of research and coupling of Ocean Literacy and Blue Economy, the present study enhances this methodology. While Paredes-Coral et al. (2021) identified that these publications focused

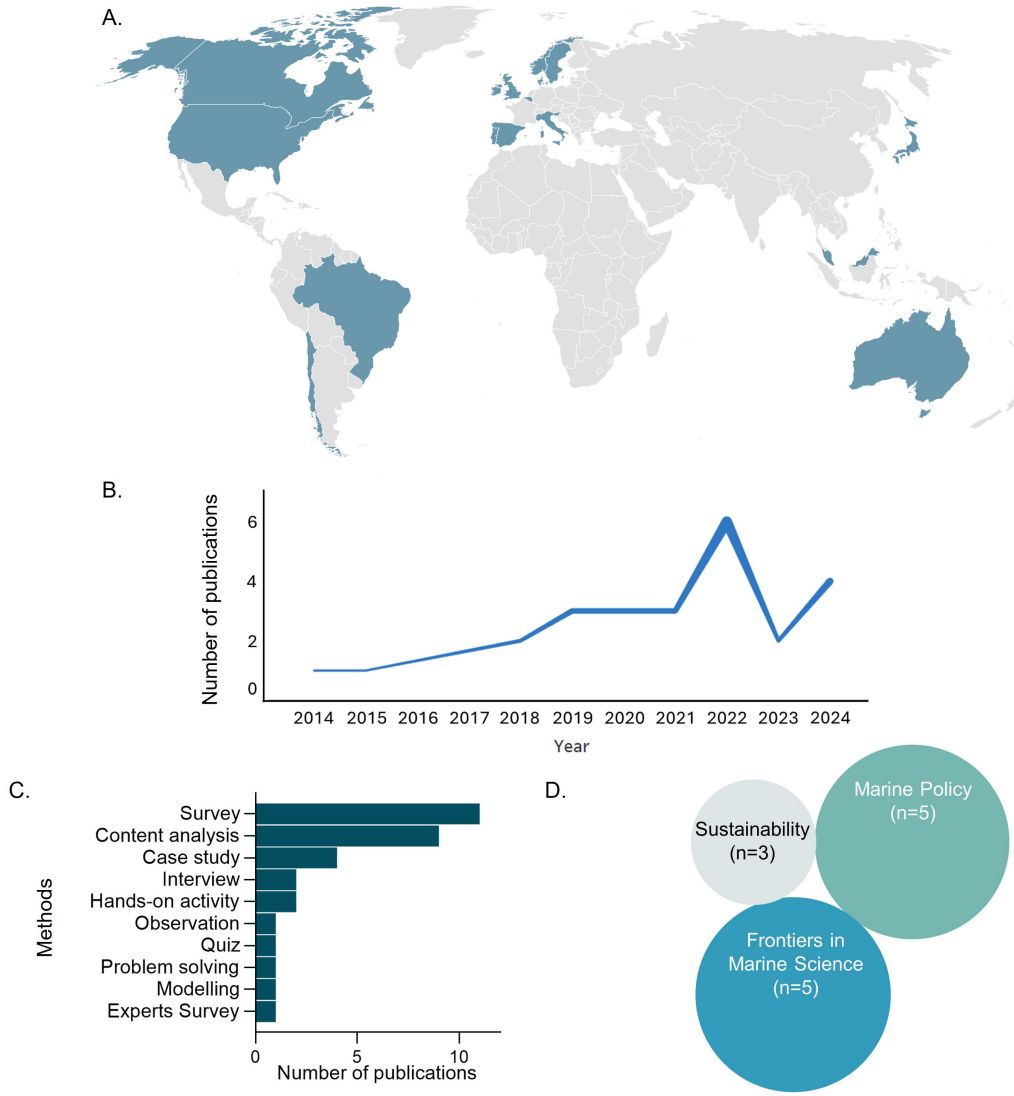


FIGURE 3
Overview of Ocean Literacy and Blue Economy association. **(A)** Geographical distribution of publications; **(B)** Distribution of publications by year; **(C)** Methodologies used in the publications; **(D)** Distribution of publications by journal (top 3).

on workforce development, training, and specific industrial sectors such as shipbuilding, offshore renewables, coastal tourism, desalination, fisheries, and seafood production, this research broadens the scope to include, not only, various economic sectors, but also, overarching economic concepts. This approach provides a more comprehensive understanding of the relationship between Ocean Literacy and economic frameworks and provides guided insight into specific economic concepts within the Ocean Literacy framework research fields and contents. Despite these growing global efforts, the integration of economy topics within the context of Ocean Literacy is still limited. Nevertheless, research on Ocean Literacy is gaining recognition in the scientific literature, producing diverse, multi and interdisciplinary assessments, such as the evaluation of an educational programme (Costa et al., 2021), strategies to boost Ocean Literacy (Boaventura et al., 2021) and examination of public perceptions of ocean topics (Jefferson et al., 2021). There is also growing research on marine citizenship (Buchan et al., 2023), expansion of the dimensions of Ocean Literacy (McKinley et al., 2023) and Ocean Literacy in policy making (Paredes-Coral et al., 2021).

The analysis of journals publishing this content reveals a high number of studies in Marine Policy and Frontiers in Marine Science journals, each with five articles. Both journals are ranked in Q1 and focus on interdisciplinary research at the intersection of policy, management, and marine sciences, key to both Ocean Literacy and the Blue Economy (Figure 3D).

While the first scientific publication on Ocean Literacy backs to 2005 (Cavas et al., 2005), the first Ocean Literacy publication

addressing blue economy is from 2014 (Hynes et al., 2014). Since then, a gradual increase in research activity was found (Figure 3B) with 25 publications to date identified in this study. In fact, Ocean Literacy Research and Blue Economy was identified as a priority area to advance the UN Ocean Decade (McRuer et al., 2024). According to the authors, this disconnection should be reduced, as Sustainable Blue Economy development may prioritize economic growth, potentially neglecting social and environmental impacts derived from these activities. The authors argue that improving Ocean Literacy among a wide range of stakeholders—including local communities, policymakers, and private sector—is essential to ensure that the benefits of Sustainable Blue Economy initiatives are shared equitably, and all interested parties participate in the decision-making process.

The variety of methods to connect Ocean Literacy and Blue Economy found in the literature are shown in Figure 3C. Surveys primarily targeting teachers or students, along with content analysis, are the most common methods and are mainly focused on assessing scientific knowledge, and baseline understanding of ocean-related topics. This knowledge typically includes themes such as marine life, marine litter, and ocean-related careers (e.g. Ahmad-Kamil et al., 2022; Paredes-Coral et al., 2022). However, the growing presence of case studies, interviews, and expert consultations (e.g., problem-solving exercises, opinion-based assessments) points to an increasing emphasis on advancing Ocean Literacy initiatives to move beyond educational knowledge and engage with broader social and practical dimensions.

The main types of intervention - Education and Learning, Engagement and connection, Training and development, and Institutional/Organization policy (Table 2) illustrates the interplay between education, engagement, professional development, and policy-making across different sectors in Ocean Literacy and Blue Economy.

TABLE 2 Types of intervention found in scientific publications concerning ocean literacy and blue economy.

| Category | Description | Examples |
|---|---|---|
| Education and learning (n=8) | Activities/interventions involved in formal and non-formal education | Experiments in laboratories<br>Surveys |
| Engagement and connection (n=6) | Studies Engaging or connecting with individuals, groups, organisations, sectors | Collaboration<br>Engagement<br>Marine stewardship<br>Decision making<br>Values |
| Training and development (n=6) | Training and development programs and activities | Teacher development<br>Capacity building<br>Professional development |
| Institutional/ Organization policy (n=4) | Studies analysing or proposing practices in the corporate and governance sector | Policy recommendations |
| Research (n=2) | Creation of baseline knowledge and understanding the current landscape | Mapping; review |

### 3.1.1 Economy related topics coverage in Ocean Literacy scientific research

The coverage of economy-related topics in Ocean Literacy scientific research was analysed by examining publications that address the economic dimension of the ocean and categorizing them by specific economy topics (Figure 4A). Blue Economy had the highest number of references in publications (12), with additional publications also addressing specific Blue Economy sectors (6). Circular economy had the fewest reference in these publications (3), while Environmental economics was represented by 4 publications.

Considering methodological approaches per type of economic concept, Educational and learning interventions had the highest number of publications across all economic concepts analysed, showing a strong emphasis on education and learning (Table 2). The publications addressing specific sectors of the Blue Economy, emphasize training and development, suggesting a stronger focus on skill development and workforce improvement. The Circular economy concept has contributions in Education and learning, Research method and Policy initiatives. The Environmental economy dimension shows the highest emphasis on engagement and connection, reflecting a focus on community-building, collaboration, or public engagement related to environmental goals. These results point towards selected preferences of methodological approaches for each analysed economic concept, suggesting a lack of integration that may impact learning outputs across the whole dimensions of Blue Economy. The level of interest or involvement of different groups (Schools/teachers, Policy-makers, Society, Professionals, and Stakeholders in general) in the four economic and environmental concepts studied in the analysed publications, shows that Blue Economy and its sectors are relevant for all society sectors while Circular Economy has a more modest engagement, suggesting that this is an area of interest but not yet a major focus across all groups. Finally, stakeholders in general are mainly engaged in Environmental Economics, likely due to management interests (Figure 4B).

#### 3.1.1.1 Blue Economy

When analysing the relevant Blue Economy keywords in the scientific publications, Blue Economy emerged as the dominant keyword. The word cloud in Figure 5A highlights short key concepts such as ‘ocean literacy, ‘sustainable development goals’, ocean decade” and “marine environment” reflecting a broader environmental and economic focus on these publications. This is in line with current frameworks proposed by others for Ocean Literacy. Penca et al. (2024) emphasize Ocean Literacy has a foundational element for developing the competencies required by researchers and practitioners. to contribute to sustainable development practices within the Blue Economy.Similarly, Paredes-Coral et al. (2021) highlights the need of spreading ocean literacy within the Blue Economy stakeholders by fostering cooperation across institutions, disciplines, marine education networks and the industry. Improving Ocean Literacy among youth was also emphasized as essential for fostering stewardship and promoting a sustainable Blue Economy, particularly by enhancing their involvement in marine spatial

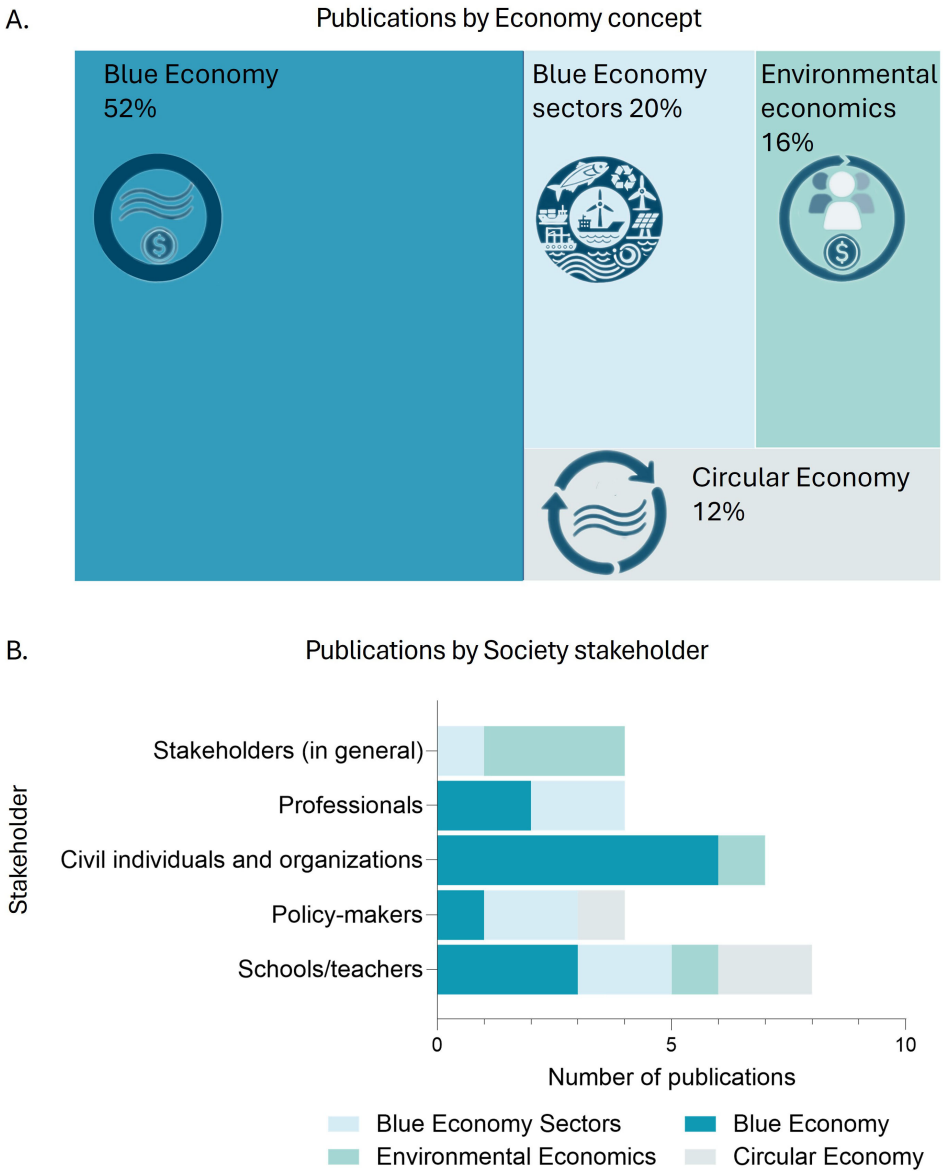


FIGURE 4
**(A)** Ocean Literacy publications categorized by economic concept and **(B)** by society stakeholder. Icons in panel **(A)** were generated using the AI tool ChatGPT 4.0 and subsequently edited by the authors. Icons in **(A)** were generated using the AI tool ChatGPT 4.0 and subsequently edited by the authors.

planning (Devenport et al., 2021). In adults, the understanding of community perceptions of the ocean, including how different age groups perceive the ocean's economic benefits, has been suggested as an approach to design tailored policies for coastal management (Nahuelhual et al., 2024).

Findings from consultation studies with education stakeholders revealed that the lack of awareness in Blue Economy concepts, such as maritime career opportunities, was considered a barrier that inhibit teaching among educators (Fauville et al., 2018). Similarly, the link between Blue Economy and climate change was also found, with the indication that educational interventions to enhance and provide accurate teachers' knowledge of climate change and the Ocean-Climate Nexus are crucial for a transition to the Blue Economy (Anyanwu, 2019).

#### 3.1.1.2 Sectors in Blue Economy

When looking for the link between Ocean Literacy and specific sectors of the Blue Economy, publications were found for aquaculture, fisheries, shipbuilding and offshore renewables specific sectors. The word cloud obtained from these publications shows a focus on Blue economy, suggesting that research and predominantly centred around industry-specific contributions to the Blue Economy, with less emphasis on broader environmental or social dimensions (Figure 5B). These works aimed to foster sustainable fish consumption and the social acceptance of aquaculture through formal educational initiatives (Correia et al., 2019; Silva et al., 2024). Additionally, some publications suggest efforts to develop synergies between Ocean Literacy, training and capacity building across various stakeholder groups to enhance

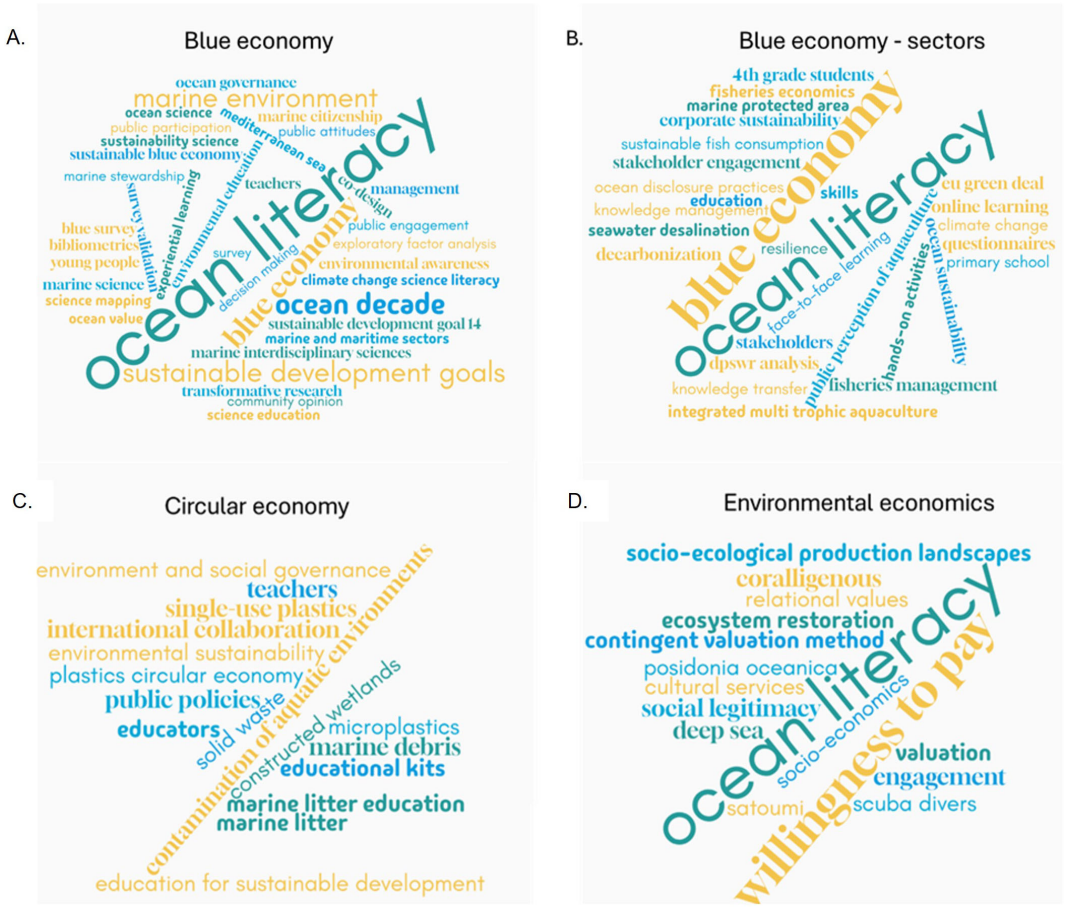


FIGURE 5
Keywords associated with Ocean Literacy publications categorized in Blue Economy **(A)**, Blue economy sectors **(B)**, Circular Economy **(C)** and Environmental economics dimensions **(D)**.

their understanding and implementation of sustainable practices (Bastardie et al., 2022; Fernández Otero et al., 2019). Therefore, these publications highlight that Ocean Literacy is extending beyond traditional educational settings and is reaching a broader audience that includes industrial professionals, policymakers and community stakeholders.

On the corporate front, this study found a publication highlighting how business awareness and voluntary actions are critical for engaging companies in ocean sustainability (Sardá et al., 2023). However, unlocking organizational activation for sustainable practices is more complex than simply raising awareness and internal Ocean Literacy enhancement should be a requirement and a driver to establish voluntary action strategies towards marine preservation, mitigation of pressures and restoration of negative effects (Sardá et al., 2023). By investing in educational initiatives that focus on ocean sustainability, companies can empower their employees to take proactive steps in their roles, whether through innovative product development, sustainable supply chain management, or community engagement efforts (de Oliveira et al., 2023).

#### 3.1.1.3 Circular Economy

The analysis of the publications addressing circular economy concepts and their intersection within Ocean Literacy and the Blue Economy, revealed limited attention to circular economy topic, with only 3 publications identified. The word cloud obtained from these illustrates a weak linkage between the Blue Economy and Circular Economy concepts within the studied literature, suggesting that resource reuse and waste reduction are not yet widely integrated into ocean literacy discussions (Figure 5C) and research. The publications revealed that Ocean Literacy initiatives have focused on addressing plastic pollution, which is a critical component of the circular economy (Ahmad-Kamil et al., 2022). However, there is a gap in environmental policy, technology and innovation topics to address marine litter (Ahmad-Kamil et al., 2022) as well as other aspects of the circular economy concept applied within Blue Economy. As indicated by several authors, actions and activities such as technology and innovation to address marine litter should be introduced in teacher training, to equip educators with the tools to engage youth in technological and innovative solution to waste management (Ahmad-Kamil et al., 2022; Almeida et al., 2024;

Nguyen, 2023). This result highlights that approaches as the ones suggested by these authors will prepare students to understand the connections between marine ecosystems, human activities and the search for sustainable economic practices.

#### 3.1.1.4 Environmental economics

Concerning the link between Environmental Economics and Ocean Literacy research, the resulting word cloud for Environmental Economics highlights key themes such as "ocean literacy," "willingness to pay," "ecosystem restoration," and "contingent valuation method," emphasizing a targeted focus on both market value and non-market value economic valorisation of marine ecosystems, as well as, socio-ecological interactions, and public engagement in conservation and restoration efforts (Figure 5D). The connection of Ocean Literacy and environmental economics is demonstrated in publications associated to nautical sports (Zunino et al., 2020) and ocean conservation and protection (Uehara et al., 2020). The findings of these studies revealed that increased ecological knowledge, fostered through Ocean Literacy, is associated with a higher perceived cultural and relational value of marine ecosystems, demonstrating that informed individuals are more likely to support conservation efforts and recognize the economic importance of maintaining healthy marine environments (Armstrong et al., 2022; Uehara et al., 2020; Zunino et al., 2020). Moreover, enhanced awareness positively influences their economic decisions about sustainability topics (Schleich and Alsheimer, 2024). In fact, Barracosa et al. (2019) suggested the incorporation of ecosystem services concepts into educational frameworks, suggesting several strategies such as capacity building for teachers, project-based learning and collaboration between educators and scientists to create specific educational programmes. In this context, the importance of ecosystem valuation, which requires citizen involvement for better decision-making, and a willingness to pay for ecosystem services should be encouraged. For instance, teacher training on marine ecosystem goods and services, their valuation and associated methodologies will enable students to practice and evaluate the trade-offs involved in different marine-related activities. Simulation games could be used as a tool to facilitate this learning process (Costanza et al., 2014). This bottom-up approach will prepare students to participate in governance processes, develop new technologies, policies and business models that support sustainable development and face the challenges of the Blue Economy.

## 3.2 The case study of the Portuguese Blue School

Portugal's strategic interest in the ocean is underscored by its extensive coastline of approximately 2,500 km² and one of the largest Exclusive Economic Zones (EEZ) in Europe, covering over 1.7 million km² and with a current process of extension of its continental shelf (Portuguese Task Group for the Extension of the Continental Shelf, 2017). Recognizing the ocean's significance, Portugal has been putting the ocean at the heart of its policy agenda and is now on its third National Ocean Strategy. In 2021 it presented its current National Ocean Strategy 2021-2030, supported by a comprehensive action plan (DGPM - Directorate General for Maritime Policy, 2023). This initiative defines the current status of Ocean activities in Portugal and lays out the predicted actions and focus areas for the next years, where Ocean Literacy is part of this group of priority areas, underscoring Portugal's commitment to fostering a well-informed society that values ocean resources and promotes sustainable economic practices linked to maritime activities.

Portugal has also played a pioneering role in adapting Ocean Literacy principles to its Atlantic context. In 2011, Ciência Viva led efforts to translate and align Ocean Literacy concepts with national science and geography curricula, marking a significant step toward integrating Ocean Literacy into formal education without changing the curriculum structure. However, it was only in 2017 that the Blue School Program was launched as a pilot initiative, following proposals developed within European marine education forums. Backed by the Ministry of the Sea, the program formalized a national approach to Ocean Literacy, and quickly expanded, with the first national meeting held in 2018 and the Blue School Day initiative launched in 2020 (Costa et al., 2021). The Blue School PT program is now embedded within a broader framework that supports Ocean Literacy through structured educational criteria, stakeholder collaboration, and community engagement.

### 3.2.1 Portuguese Blue School website - activities

This study delved deeper into this pioneer program to explore if, and how, it is promoting general and/or specific content in Ocean Literacy connected to Blue Economy. A search conducted within the educational activities offer of this programme showed that the activities are categorized within 14 categories/types of activities (Figure 6), comprising approximately 400 activities offered by 46 entities.

Of the offered activities in the program a surprising number are related to Blue Economy, representing a coverage of nearly 20% (Figure 7A-1). Among these entities the majority are Universities (26%) and Public sector entities/services (19%), followed closely by private sector and NGOs (14% and 9% respectively) (Figure 7B).

The distribution of partners in the Blue School network differs from those involved specifically in Blue Economy activities. According to Costa et al. (2021), private sector companies represent the largest portion of the Blue School network, comprising 34% of the organizations. Non-profit associations follow at 19%, and public entities make up 14%. In contrast, universities and research centres represent only 8% of the network. However, comparing the entities involved in the overall program to those specifically delivering Blue Economy activities, universities play a much more prominent role in delivering activities, despite their smaller representation in the network. This difference may be explained by the fact that universities may incorporate economic concepts into their range of offerings. In contrast, companies -though more numerous overall - may focus more on providing activities related to ecological/environmental

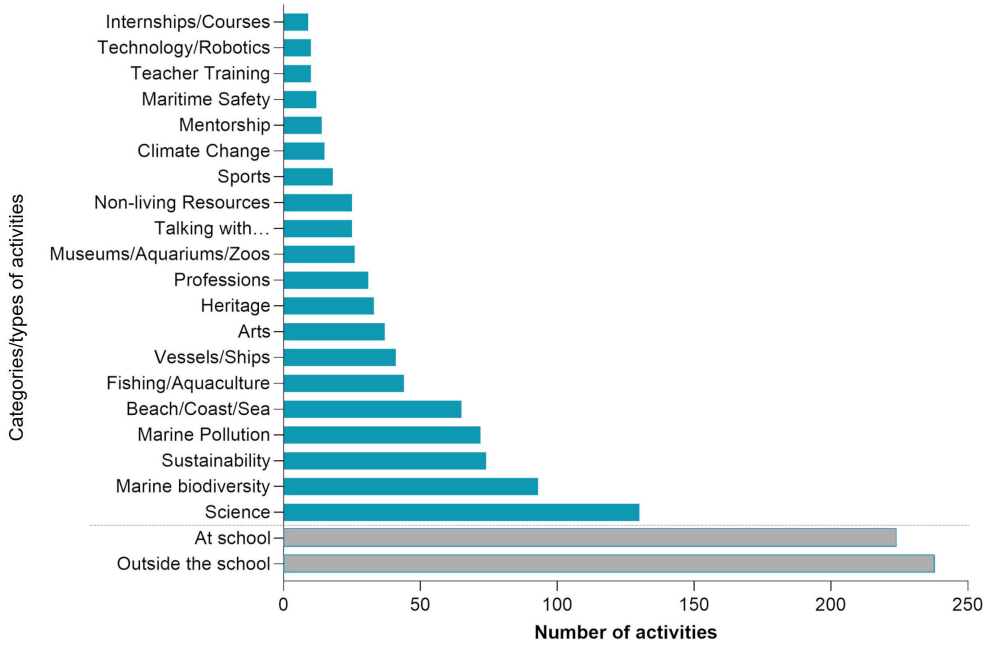


FIGURE 6
Categories/types of activities offered by the Blue School programme. Note: each activity can have more than one category/type. The categories "at school" and "outside the school" are included to reflect the original classification used in the programme and are visually distinguished by a grey bar colour to distinguish them from the thematic categories (blue bar colour).

aspects rather than address economic dimensions of the Blue Economy. Figure 7A shows the diversity of economic concepts covered by these activities. Amongst there, professions (46%) is the most covered concept in the activities offered, suggesting a strong focus on job (and therefore economy) opportunities related to the ocean, followed by concepts like the circular economy (10%), or sectorial concepts with Blue Economy like aquaculture (7.5%). Fishing (6%), fish and consumption (5%) and biotechnology (5%) are other sectors covered, followed by research and algae (4% each) and energy, robotics, desalination, tourism, technology and maritime culture and naval construction (1% each). Despite representing a diverse and rich set of Blue Economy concepts and sectorial activities, the topics receiving more limited attention may reflect emergent areas of interest that are not yet fully developed within ocean sciences and industries.

### 3.2.2 Portuguese Blue School website - resources

In addition to the activities area, the Blue School website has an area of digital educational resources. This 'Resources' area is divided into six sections (videos, preschool, 6–10 years old, 10–12 years old, 12–15 years old, 15–18 years old and Ocean Library). Each section opens a new page with a list of resources. Section 'Videos' present 84 videos divided into educational videos (31), documentaries (14), ocean literacy (11), ROV luso (10), Ocean expeditions (8), Ocean careers (6) and History (4). These are provided by 34 entities, from YouTube channels. The main providers are the Portuguese Task Group for the Extension of the Continental Shelf (EMEPC) (12 videos), Blue School (11) and the United Nations Educational, Scientific and Cultural Organization (8). Section 'Ocean Library' features a collection of 164 youth-oriented books, including tales and children's stories about the sea, listing only the title and author without categorization by educational level.

In these two sections (Videos and Ocean Library), the link to Blue Economy themes was not analysed due to lack of descriptive information. The other five sections (preschool, 6–10 years old, 10–12 years old, 12–15 years old, 15–18 years old), corresponding to different educational levels in Portugal, were screened for Blue Economy related content. Table 3 provides an overview of the distribution of educational resources related to Blue Economy themes available on the BlueSchool website, segmented by school age.

Table 3 highlights the number of resources, the number of partners/providers, the diversity of themes and evolution over different educational levels. The number of resources increases with age up to 12–15 group (90 resources), followed by 10–12 group (82) and then declines in the 15–18 group (53). This aligns with partners/entities involvement, that also varies across age groups, ranging from 12 in pre-school to 32 in the 12–15 age group. The entities offering more resources on the website are Blue School, "Estudo em Casa" and EMEPC. However, a wide range of organisations from the private sector, Colabs (Collaborative Laboratories), Research Centres and Public services are also represented, such as Águas do Tejo Atlântico, Ciência Viva, MARE - Marine and Environmental Sciences Centre, CESAM - Centre for Environmental and Marine Studies, B2E Colab or Lisbon Zoo.

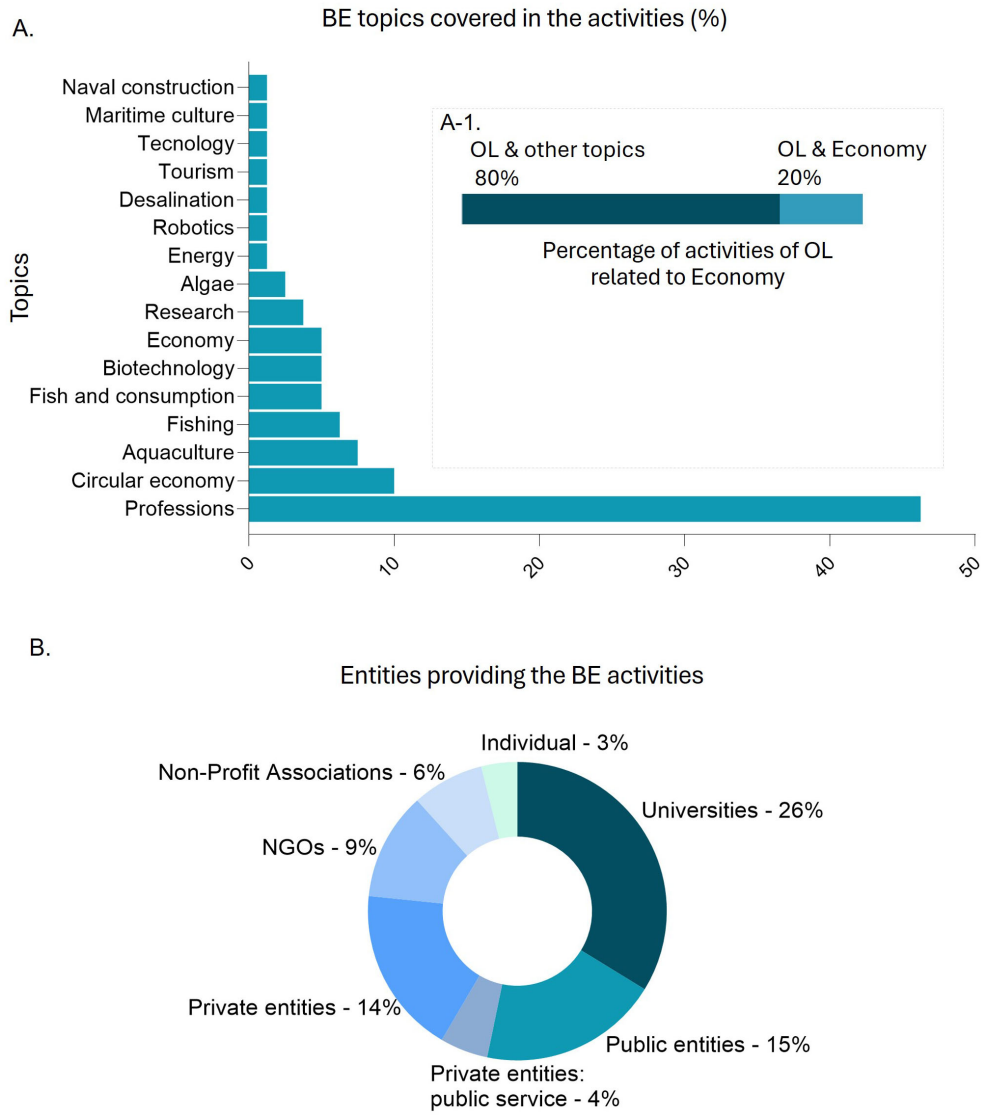


FIGURE 7
Blue School PT programme coverage of Economic topics. **(A)** Economic topics covered by the activities offered by the Blue School PT programme; (A-1) Percentage of activities of the Blue School PT programme covering Economic topics; **(B)** Types of entities providing Blue Economy related activities for the programme.

Also, a gradual progression is observed in the diversity and complexity of Blue Economy themes across educational levels. In Pre-school, Blue Economy is minimally represented, with only one resource addressing the topic of 'sea careers', while older age groups have access to resources exploring increasing complex topics such as circular economy, aquaculture and energy. From the ages 10-12, resources present more advanced concepts including SWOT analysis, poverty reduction, mineral exploitation and cosmetics and pharmaceutical industries. Regarding the types of resources, the lists contain links to repositories or activity pages, teacher guides, webinars, e-books, videos, games, interactive tools, podcasts and participatory projects. The more prevalent are teacher guides, with activities planned for each level of teaching. The resources are not restricted to one level of education. They are repeated between teaching cycles as long as the resource remains interesting for the age group. On the other hand, there is also content specific to a single teaching level.

Many resources have general descriptions, particularly those that link to content repositories or external activity pages, such as 'Here you can find different resources, materials, tools and good practices about the Ocean and much more'. In these cases, it was not possible to verify the inclusion of Blue Economy -related resources by title or description.

TABLE 3 Resources available on the Blue School website related to Blue Economy.

| School age | Resources | Partners/ providers | Resources related to blue economy | Blue economy theme |
|---|---|---|---|---|
| Pre-school | 22 | 12 | 1 | Sea careers |
| 6 to 10 | 66 | 27 | 7 | Traditional activities, Circular economy, aquaculture, sustainable management, fish consumption, energy, transportation, sea professions |
| 10 to 12 | 82 | 28 | 12 | Circular economy, Aquaculture, Sustainable management, Consumption, Sea professions, SWOT analysis, Sustainable development, Poverty reduction |
| 12 to 15 | 90 | 32 | 15 | Consumption and fishing, socio-economic consequences, aquaculture, fish prices, Sea professions, swot analysis, innovative products, sustainable development, tourism, safety, energy, transportation, circular economy, food, cosmetics and pharmaceuticals industry, desalination |
| 15 to 18 | 53 | 27 | 16 | Overexploitation of fish, Socio-economic consequences, Aquaculture, Fish production and consumption, Sea Professions, tourism, security, energy, transportation, Innovative products, Exploitation of mineral resources, Sustainable development, Desalination, Circular economy, Food, cosmetics and pharmaceuticals industry |

## 3.3 Alignment of literature with Blue School programme activities and resources

The activities and resources provided by the program align with ocean-related themes selected by participating Blue Schools for their projects. While it is typical for schools to address multiple themes, the most chosen topics, listed in order of prominence, include marine pollution, biodiversity, conservation, sustainability, water sports, general topics, heritage, climate change, and fishing (Costa et al., 2021). Notably, Blue Economy topics are not amongst the ones most frequently pursued by schools. This may be partly due to the limited integration of economic content within the national curriculum. In basic education, economic topics are introduced in geography classes, only in the 9th grade. Although economics is offered in secondary education, it is restricted to students who choose a specific academic path, meaning that a significant portion of students may receive little exposure to economic concepts. Additionally, fewer secondary schools participate in the programme, and among those that do, most are often led by science teachers. Consequently, the activities developed tend to focus more on scientific and environmental topics over economic ones.

The analysis of the scientific literature targeting education further reinforces these findings. The scientific literature included in this study examines diverse aspects of the blue economy, including ocean-related careers and valuation (Guest et al., 2015), ecosystem services (Hynes et al., 2014), and public perceptions of the ocean economy (Nahuelhual et al., 2024; Paredes-Coral et al., 2022). Other research highlights specific areas such as fish consumption (Silva et al., 2024), aquaculture (Correia et al., 2019), and nature-based solutions within the circular economy (Almeida et al., 2024). These findings indicate that the Blue School PT programme aligns broadly with ocean economy themes addressed in the literature, providing Blue Economy related activities and resources on the website. Notably, the literature highlights other areas, particularly nature-based solutions, which are gaining traction in sustainability discussions, and these could be further explored in Ocean Literacy programs like the Blue Schools one. Expanding the integration of Blue Economy concepts in educational curricula could further bridge the gap between Ocean Literacy and sustainable economic development, fostering greater awareness and engagement with ocean-related careers and industries.

The resources section of the Blue School website is very complete and varied, but it could benefit from being organised into a structured content repository. Resources could be systematically catalogued and classified with metadata such as title, author, date, language, description, keywords, media format, and educational level. This could help to identify each resource, describe its content, link it to similar materials, differentiate it from others, and facilitate searchability and content filtering. Also, with a search engine users could locate resources by entering relevant keywords, improving the overall usability and accessibility of the platform for the Blue School community. Adopting widely accepted metadata standards would also ensure interoperability with other repositories, allowing resources to be shared and integrated across platforms, contributing more effectively to ocean literacy.

# 4 Recommendations to research and policy

## 4.1 Expanding Ocean Literacy research and education efforts in Blue Economy

Ocean Literacy has gained renewed attention in recent years, particularly in the United Nations' "Ocean Decade," highlighting the importance of fostering a deeper societal understanding of the ocean's role in sustaining life. Initially grounded in education and scientific knowledge awareness, Ocean Literacy has evolved into a multidimensional framework for ocean governance. This evolution reflects a growing recognition of the need to address cognitive aspects—such as knowledge and communication—and behavioural

and emotional dimensions, including awareness, activism, emotional connection, and adaptive capacity (McKinley et al., 2023). Furthermore, trust, transparency, and equitable access to ocean-related experiences are critical components for fostering meaningful public engagement (McKinley et al., 2023). Despite this progress, Ocean Literacy 's integration into governance strategies often lacks clear pathways for implementation, particularly in addressing systemic challenges such as inclusivity and long-term behavioural change. Similarly, the definition of the Blue Economy is changing, from its original focus on economic growth to include sustainability principles. Ocean Literacy Research is emerging alongside these developments, prompting the establishment of key priorities.

These priorities focus on measuring ocean literacy, the role of ocean literacy as a policy mechanism, and the alignment of Ocean Literacy Research with climate change and the blue economy agendas (McRuer et al., 2024). In this context, recent years have seen a growing need of approaches – whether through Ocean Literacy research or as Ocean Literacy practices - that integrate Ocean Literacy with Blue Economy to develop sustainable approaches to ocean resource management and economic development. For instance, in Europe, the *MATES* project (https://projectmates.eu/) incorporated Ocean Literacy in educational, professional and industrial environments, namely the shipbuilding and offshore renewable energy, to build a workforce equipped to address the sustainability challenges of their activities. In the tourism sector, the *Coastal Pro* project (https://coastalpro.eu/), aims to offer training and support to develop a framework for next-generation skills in coastal tourism integrating Ocean Literacy into its training programmes. Similarly, the Blue Generation (https://www.bluegeneration.org/) and Next BlueGeneration (https://nextbluegeneration.eu/) projects aim to attract young people to sustainable Blue Economy careers by providing educational tools, training, and digital resources that raise awareness of opportunities across key maritime sectors. At the Portuguese national level, The SeaStainability initiative, launched by Oceanário de Lisboa (https://oceanario.pt/en/corporate/seastainability/), focuses on promoting sustainable practices by encouraging businesses and organizations to adopt environmentally responsible practices in their operations, particularly in relation to the ocean and marine ecosystems.

At school education level, the *European Blue Schools programme* aimed to introduce the Blue Economy to school education, targeted secondary school students, and support students to be aware of the Blue Economy, culture and sustainability of coastal areas (http://www.blue-schools.eu/en/the-project/). At the Portuguese national level, the project "Educating a Blue Generation" (https://geracaoazul.org/) is a project developed by Oceano Azul Foundation and Oceanário de Lisboa in collaboration with the Portuguese Ministry of Education, that paves the way to including the ocean in the curriculum of the first grade of the Portuguese basic education, in which Blue Economy was also considered.

The research priorities identified by McRuer et al. (2024) provides several research questions on Ocean Literacy and a Sustainable Blue Economy. These suggestions are directed towards industry and communities (Table 4). However, as relatively new areas, the introduction of these "Blue" economic concepts related to sustainability in schools remains essential to prepare adult generations for these issues that require immediate attention. For instance, the national programme REASE (http://rease.ccmar.ualg.pt/#home) highlight the importance of Ocean Literacy in fostering a better understanding of ecosystem services among citizens and educators in the context of coastal ecosystems, with notable outputs as mapping blue carbon in Southern Portugal (Barracosa et al., 2019).

TABLE 4 Comparison of research questions related to ocean literacy and a sustainable blue economy priority area from McRuer et al., 2024 and the current study.

| Ocean literacy and a sustainable blue economy | |
|---|---|
| Example topics/questions (McRuer et al., 2024) | Topics/questions emerging from this study |
| Alignment of Agendas: How can the ocean literacy and blue economy agendas be better aligned to support sustainable coastal communities?<br>Enhancing Community Engagement: How can ocean literacy in communities be enhanced to ensure that citizens can actively and meaningfully contribute to the transformation of the blue economy? How ocean literate citizens is considered and integrated into blue economy decision-making?<br>Promoting Blue Careers: How can ocean literacy be used as a tool to promote and attract talent to blue career opportunities or business diversification?<br>Business Engagement: How can industry and businesses become more "ocean literate"? How can industry/businesses become more "ocean literate"? How business communities can be better engaged in ocean issues? How can businesses be encouraged to understand the importance of ocean literacy as a core component of their corporate strategy and product or service design?<br>Supporting Vulnerable Communities: How can ocean literacy research help vulnerable and marginalized coastal communities seek sustainable livelihood solutions while integrating protection mechanisms for coastal ecology? | Blue Economy in formal and/or non-formal education: How can the concept of natural capital be developed at the school education level?<br>Blue Economy in formal and/or non-formal education: How can the concepts of bioeconomy and circular economy be developed at the school education level?<br>School engagement: How can the interest of schools and teachers in the Blue Economy as a topic for Ocean Literacy projects be increased?<br>Business Engagement: How corporate awareness and activation strategies to respond to the challenges of to the challenges of ocean sustainability be assessed?<br>Enhancing Community Engagement: How can Ocean Literacy help individuals and communities to understand the policy process of marine management? How can Ocean Literacy help individuals and communities to face the barriers they face in engagement? |

## 4.2 Ocean Literacy in policy frameworks

Several policy frameworks exist globally and regionally to support and promote public understanding and responsible actions towards the ocean and its ecosystems. More recently, Ocean Literacy has been importantly positioned, with growing recognition, as a societal outcome in the Challenge 10 White Paper, part of the "Ocean Decade", reflective of better understanding of the ocean's value, strengthen society-ocean connections, and empower all sectors to ensure a healthy ocean (Glithero et al., 2024). The Blue Growth Strategy, which aims to promote sustainable growth in the marine and maritime sectors, highlights the importance of Ocean Literacy. It emphasizes the need for increased Ocean Literacy programs and training and the use of Ocean Literacy to bridge the gap between society, stakeholders, decision-makers and the ocean (European Commission, 2017). Alongside green finance, investment, research and innovation, education and training are central to mainstreaming sustainability in all EU policies under the European Green Deal. Ocean Literacy could be vital in this effort, as it helps build a deeper understanding of the oceans' key processes and its role in global sustainability, providing robust scientific understanding of ocean related biophysiochemical processes and it's interlinks with humanity and at the planetary scale, fostering individual's capacities to make informed decisions at every level. As the EU aims for a climate-neutral economy with the promotion of a circular and bioeconomy, it is crucial that citizens, private sector, and policymakers understand marine ecosystems, the Blue Economy, and the links between ocean health and climate change. By integrating Ocean Literacy into education, training and policy the EU can encourage the stakeholders, such as individuals, communities, policy makers and industries to make informed decisions and be engaged them in the sustainable use of ocean resources.

# 5 Conclusion

This study aimed to investigate the current status of scientific research in Ocean Literacy and its links with Blue Economy while also analysing deeper a pioneer Ocean Literacy program – the PT Blue Schools Program to evaluate, in a real case scenario, if, and how, are the Blue Economy concepts and related themes being tackled.

To ensure a comprehensive and interdisciplinary review, we used the term "ocean literacy" to maintain conceptual focus. However, we acknowledge that this choice may have excluded relevant publications - particularly those from sectoral or policy-oriented forums - where related concepts are discussed without explicitly using the term. While including broader terms such as "marine education" or "ocean awareness" could have expanded the results, we intentionally limited our search to "ocean literacy" to avoid over-representing related themes and to preserve the clarity of the review scope.

The results emphasized that while there have been efforts to integrate Blue Economy topics and concepts into Ocean Literacy there is still work to be done across all society levels. In schools, Ocean Literacy needs to go beyond natural sciences and environmental aspects and incorporate the socio-economic aspects of sustainability as part of ocean's knowledge. This means that initiatives should not only focus on the basic science and environmental components knowledge of the Ocean but also consider the social and economic dimensions of this sphere, such as equity, community well-being, and economic viability and impact and how the lens of sustainability can alter the current development paradigm of the world. By doing so, students will gain a holistic understanding of sustainability that integrates all aspects of the Blue Economy and may foster a better future for our Ocean.

When applied to the economic levels of society, industry and economic sectors activities, this study highlights the need to raise awareness about Ocean Literacy and its potential for promoting sustainable practices and shifting current deployment and detrimental practices within ocean related businesses. However, awareness alone is not enough; it is also necessary to identify actionable strategies and concrete training methods to activate sustainable practices within industries. This could involve, for example, rethinking business models, supply chains, reducing and circularizing waste and side streams, improving resource efficiency, and integrating more sustainable and innovative technologies like biotechnology or biomanufacturing to name a few.

In conclusion, Ocean Literacy has the potential to shift the mindset and build the necessary skills of the next generation of industry and policy leaders, providing them with the tools they need to shift our current societal development paradigm towards new and more sustainable socioeconomic development models. A comprehensive approach that combines education, awareness, and practical implementation is, therefore, essential for the successful integration of Ocean Literacy into the Blue Economy. A holistic approach addressing environmental, social, and economic aspects simultaneously has the potential to implement sustainability in practice in both educational and industrial settings. The Blue Schools program is a good example of these approach. Today, the program encompasses 493 schools, engaging approximately 109,000 students, 3,500 teachers, and 127 partner entities. Furthermore, a significant number of educational activities and resources are available through the program's platform, and 23 municipalities have joined the initiative. The recent development of the Blue Schools Global Network could be a valuable opportunity to expand educational activities related to blue economy concepts, fostering greater awareness and engagement among students globally. Given the prominence of Portuguese contributions in the literature and the structured implementation of the PT Blue Schools programme, this initiative may serve as a valuable proxy to

understand broader trends and practices in Ocean Literacy at the European or even international level.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding authors.

## Author contributions

MA: Writing – original draft, Methodology, Data curation, Investigation, Writing – review & editing, Conceptualization. DL: Formal analysis, Writing – original draft, Methodology, Conceptualization, Writing – review & editing. RC: Formal analysis, Writing – original draft, Writing – review & editing. AL: Funding acquisition, Writing – review & editing. HV: Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

## Funding

The author(s) declare financial support was received for the research and/or publication of this article. This study was funded by the ERA Chair BESIDE project financed by the European Union's Horizon 2020 research and innovation programme under grant agreement No 951389 (https://doi.org/10.3030/951389). We also acknowledge financial support from FCT/MCTES, through national funds of CESAM (under the project/grant UID/50006 + LA/P/0094/2020 (doi.org/10.54499/LA/P/0094/2020) and CIDTFF by FCT/MCES 1668 (UIDB/00194/2020).

## Acknowledgments

We would like to acknowledge the coordination team of Escola Azul, namely Fernanda Silva and Bernardo Mata, for their support during the development of this study, for providing information on the programme and updated data on the number of schools, partners, municipalities, students, and teachers involved.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The author(s) declare that Generative AI was used in the creation of this manuscript. Icons used in Figure 4A were initially generated with the AI tool ChatGPT 4.0 and were subsequently edited by the authors to ensure accuracy and clarity.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

## Publisher's note



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2025.1648508/full#supplementary-material

## References

Ahmad-Kamil, E. I., Zakaria, S. Z. S., and Othman, M. (2022). "What teachers should know for effective marine litter education: A scoping review," in *Sustainability*. 14. (Switzerland: Sustainability). doi: 10.3390/su14074308

Almeida, C. M. R., Azevedo, T., and Guimarães, L. (2024). Constructed wetlands as nature based solutions – hands-on activities to highlight their potential to minimize ocean pollution. *J. Coast. Conserv.* 28, 42. doi: 10.1007/s11852-024-01044-3

Anyanwu, R. N. (2019). The level of climate change science literacy among teachers in Seychelles: implications for the blue economy. *Asian J. Interdiscip. Res.* 2 (2), 1–13. doi: 10.34256/ajir1921

Armstrong, C. W., Aanesen, M., Hynes, S., and Tinch, R. (2022). People do care about the deep sea. A comment on Jamieson et al., (2020). *ICES J. Mar. Sci.* 79, 2336–2339. doi: 10.1093/icesjms/fsac161

Barañano, L., Garbisu, N., Alkorta, I., Araujo, A., and Garbisu, C. (2021). Contextualization of the bioeconomy concept through its links with related concepts and the challenges facing humanity. *Sustainability* 13, 7746. doi: 10.3390/su13147746

Barbier, E. B. (2012). Progress and challenges in valuing coastal and marine ecosystem services. *Rev. Environ. Economics Policy* 6, 1–19. doi: 10.1093/reep/rer017

Barracosa, H., de los Santos, C. B., Martins, M., Freitas, C., and Santos, R. (2019). Ocean literacy to mainstream ecosystem services concept in formal and informal education: the example of coastal ecosystems of southern Portugal. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00626

Bastardie, F., Feary, D. A., Brunel, T., Kell, L. T., Döring, R., Metz, S., et al. (2022). Ten lessons on the resilience of the EU common fisheries policy towards climate change and fuel efficiency - A call for adaptive, flexible and well-informed fisheries management. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.947150

Bellei, P., Torres, I., Solstad, R., and Flores-Colen, I. (2023). Potential use of oyster shell waste in the composition of construction composites: A review. *Buildings* 13, 1546. doi: 10.3390/buildings13061546

Boaventura, D., Neves, A. T., Santos, J., Pereira, P. C., Luís, C., Monteiro, A., et al. (2021). Promoting ocean literacy in elementary school students through investigation activities and citizen science. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.675278

Buchan, P. M., Evans, L. S., Pieraccini, M., and Barr, S. (2023). Marine citizenship: The right to participate in the transformation of the human-ocean relationship for sustainability. *PloS One* 18, e0280518. doi: 10.1371/journal.pone.0280518

Cava, F., Schoedinger, S., Strang, C., and Tuddenham, P. (2005). *Science content and standards for ocean literacy: A report on ocean literacy*. Available online at: http://www.Cosee.Net/Files/Coseeca/OLit04-05FinalReport.Pdf (Accessed January 15th, 2025).

Cavas, B., Acık, S., Koc, S., and Kolac, M. (2023). Research trends and content analysis of ocean literacy studies between 2017 and 2021. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1200181

Correia, M., Peres, H., Almeida, M., and Guimarães, L. (2019). Improving perception and acceptability of aquaculture through hands-on experimental activities for schools. *Front. Mar. Sci.* 6. doi: 10.3389/conf.fmars.2019.08.00051

Costa, R. L., and Faria, C. (2025). The blue school program: A model for holistic ocean literacy education. *Sustainability* 17, 661. doi: 10.3390/su17020661

Costa, R. L., Mata, B., Silva, F., Conceição, P., and Guimarães, L. (2021). Fostering ocean-literate generations: the portuguese blue school, in Ocean Literacy: Understanding the Ocean, 241–273. Springer International Publishing. doi: 10.1007/978-31764030-70155-0_10

Costanza, R., Chichakly, K., Dale, V., Farber, S., Finnigan, D., Grigg, K., et al. (2014). Simulation games that integrate research, entertainment, and learning around ecosystem services. *Ecosystem Serv.* 10, 195–201. doi: 10.1016/j.ecoser.2014.10.001

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., et al. (1997). The value of the world's ecosystem services and natural capital. *Nature* 387, 253–260. doi: 10.1038/387253a0

Davis, K. J., Vianna, G. M. S., Meeuwig, J. J., Meekan, M. G., and Pannell, D. J. (2019). Estimating the economic benefits and costs of highly-protected marine protected areas. *Ecosphere* 10 (10), e02879. doi: 10.1002/ecs2.2879

de Oliveira, U. R., Menezes, R. P., and Fernandes, V. A. (2023). A systematic literature review on corporate sustainability: contributions, barriers, innovations and future possibilities. *Environment Dev. Sustainability*. 26, 3045–3079. doi: 10.1007/s10668-023-02933-7

Devenport, E., Brooker, E., Brooker, A., and Leakey, C. (2021). Insights and recommendations for involving young people in decision making for the marine environment. *Mar. Policy* 124, 104312. doi: 10.1016/j.marpol.2020.104312

European Commission (2017). *Report on the Blue Growth Strategy. Towards more sustainable growth and jobs in the blue economy, Commission staff working document, SWD, 128 final*, Directorate-General for Maritime Affairs and Fisheries.

European Commission (2021). *Sustainability criteria for the blue economy – Annexes to the main report*. Publications Office of the European Union. Available online at: https://data.europa.eu/doi/10.2926/557384.

European Commission (2024). *The EU blue economy report 2024, Publications Office of the European Union, 2024*. Available online at: https://data.europa.eu/doi/10.2771/186064.

European Parliament and the Council of the European Union (2024). *REGULATION (EU) 2024/1991 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869*. Official Journal of the European Union, L 1991. Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1991.

Fauville, G., McHugh, P., Domegan, C., Mäkitalo, Å., Friis Møller, L., Papathanassiou, M., et al. (2018). Using collective intelligence to identify barriers to teaching 12–19 year olds about the ocean in Europe. *Mar. Policy* 91, 85–96. doi: 10.1016/j.marpol.2018.01.034

Fernández Otero, R. M., Bayliss-Brown, G. A., and Papathanassiou, M. (2019). Ocean literacy and knowledge transfer synergies in support of a sustainable blue economy. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00646

Glithero, L. D., Bridge, N., Hart, N., Mann-Lang, J., McPhie, R., Paul, K., et al. (2024). Ocean decade vision 2030 white papers - challenge 10: restoring society's relationship with the ocean. *UNESCO-IOC (The Ocean Decade Series 51.10.)*. doi: 10.25607/ekwn-wh61

Guest, H., Lotze, H. K., and Wallace, D. (2015). Youth and the sea: Ocean literacy in Nova Scotia, Canada. *Mar. Policy* 58, 98–107. doi: 10.1016/j.marpol.2015.04.007

Hemer, M. A., Manasseh, R., McInnes, K. L., Penesis, I., and Pitman, T. (2018). Perspectives on a way forward for ocean renewable energy in Australia. *Renewable Energy*. *127*, 733–745. doi: 10.1016/j.renene.2018.05.036

Hynes, S., Norton, D., and Corless, R. (2014). Investigating societal attitudes towards the marine environment of Ireland. *Marine Policy*. *47*, 57–65. doi: 10.1016/j.marpol.2014.02.002

Jefferson, R., McKinley, E., Griffin, H., Nimmo, A., and Fletcher, S. (2021). Public perceptions of the ocean: lessons for marine conservation from a global research review. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.711245

McKinley, E., Burdon, D., and Shellock, R. J. (2023). The evolution of ocean literacy: A new framework for the United Nations Ocean Decade and beyond. *Mar. pollut. Bull.* 186, 114467. doi: 10.1016/j.marpolbul.2022.114467

McRuer, J., McKinley, E., Glithero, D. L., and Paiz-Domingo, M. (2024). Ocean literacy research community: co-identifying gaps and priorities to advance the UN Ocean Decade. *Front. Mar. Sci.* 11. doi: 10.3389/fmars.2024.1469451

Nahuelhual, L., von Below, J., Engler, A., Campos, G., and Bianchi, J. (2024). Public attitudes and perceptions towards the ocean as an input for public policy. *Ocean Coast. Manage.* 254, 107175. doi: 10.1016/j.ocecoaman.2024.107175

Nguyen, T. P. L. (2023). Integrating circular economy into STEM education: A promising pathway toward circular citizenship development. *Front. Educ.* 8. doi: 10.3389/feduc.2023.1063755

OECD (2016). *The ocean economy in 2030* (Paris: OECD Publishing). doi: 10.1787/9789264251724-en

OECD (2025). *The ocean economy to 2050* (Paris: OECD Publishing). doi: 10.1787/a9096fb1-en (Accessed August 18, 2025).

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* n71, n71. doi: 10.1136/bmj.n71

Paredes-Coral, E., Deprez, T., Mokos, M., Vanreusel, A., and Roose, H. (2022). The Blue Survey: Validation of an instrument to measure ocean literacy among adults. *Mediterr. Mar. Sci.* 23, 321–326. doi: 10.12681/mms.26608

Paredes-Coral, E., Mokos, M., Vanreusel, A., and Deprez, T. (2021). Mapping global research on ocean literacy: implications for science, policy, and the blue economy. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.648492

Penca, J., Barbanti, A., Cvitanovic, C., Hamza-Chaffai, A., Elshazly, A., Jouffray, J. B., et al. (2024). Building competences for researchers working towards ocean sustainability. *Mar. Policy* 163, 106132. doi: 10.1016/j.marpol.2024.106132

Portuguese Task Group for the Extension of the Continental Shelf (2017). *Portuguese task group for the extension of the continental shelf*. (EMEPC - Portuguese Task Group for the Extension of the Continental Shelf) Portugal. Available online at: https://en.emepc.pt/ (Accessed August 18, 2025).

Santoro, F., Selvaggia, S., Scowcroft, G., Fauville, G., and Tuddenham, P. (2017). *Ocean literacy for all: a toolkit* Vol. 80 (UNESCO Publishing).

Sardá, R., Pogutz, S., De Silvio, M., Allevi, V., Saputo, A., Daminelli, R., et al. (2023). Business for ocean sustainability: Early responses of ocean governance in the private sector. *Ambio* 52, 253–270. doi: 10.1007/s13280

Schleich, J., and Alsheimer, S. (2024). The relationship between willingness to pay and carbon footprint knowledge: Are individuals willing to pay more to offset their carbon footprint if they learn about its size and distance to the 1.5°C target? *Ecol. Economics* 219, 108151. doi: 10.1016/j.ecolecon.2024.108151

Shellock, R. J., Fullbrook, L., McKinley, E., Cvitanovic, C., Kelly, R., and Martin, V. (2024). The nature and use of Ocean Literacy in achieving sustainable ocean futures: A Systematic Map. *Ocean Coast. Manage.* 257, 107325. doi: 10.1016/j.ocecoaman.2024.107325

Silva, A. R., Boaventura, D., and Sequeira, V. (2024). Promoting sustainable fish consumption in portuguese 4th-grade students. *Sustainability (Switzerland)* 16, 579. doi: 10.3390/su16020579

Uehara, T., Sakurai, R., and Tsuge, T. (2020). Cultivating relational values and sustaining socio-ecological production landscapes through ocean literacy: a study on Satoumi. *Environment Dev. Sustainability* 22, 1599–1616. doi: 10.1007/s10668-018-0226-8

UNESCO (2024). *Venice declaration for ocean literacy in action* (Paris, France: United Nations Educational, Scientific and Cultural Organization (UNESCO). Available online at: https://Oceanliteracy.Unesco.Org/Wp-Content/Uploads/2024/06/ENG_Venice-Declaration-for-Ocean-Literacy-in-Action.Pdf.

UNESCO-IOC (2021). *Ocean literacy framework for the UN decade of ocean science for sustainable development 2021–2030*. Paris, France: Intergovernmental Oceanographic Commission of UNESCO. Available online at: https://unesdoc.unesco.org/ark:/48223/pf0000377708.

Vieira, H., Lestre, G. M., Solstad, R. G., Cabral, A. E., Botelho, A., Helbig, C., et al. (2023). Current and expected trends for the marine chitin/chitosan and collagen value chains. *Mar. Drugs* 21, 605. doi: 10.3390/md21120605

Zunino, S., Melaku Canu, D., Marangon, F., and Troiano, S. (2020). Cultural ecosystem services provided by coralligenous assemblages and posidonia oceanica in the italian seas. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00823