Marine Pollution Bulletin 202 (2024) 116297

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Assessing the impact of an integrated educational program on Greek students' knowledge about coastal lagoons and attitudes towards marine environment conservation

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ARTICLE INFO

Keywords:
Coastal lagoons
Marine environment conservation
Educational program
Students
Knowledge
Attitudes

ABSTRACT

The primary objective of this study is to contribute to the conservation and sustainable use of seas by promoting Ocean Literacy. It investigates the impact of an educational program on Greek primary and secondary public school students' knowledge about coastal lagoons and attitudes towards marine environment conservation. An educational resource titled "Exploring the Coastal Lagoons" was developed to facilitate the non-formal educational intervention. The program involved classroom, fieldwork/outdoor and laboratory activities, focusing on enhancing understanding of coastal lagoons' abiotic and biotic characteristics and human interconnection. Results showed improved knowledge and slightly more positive attitudes after the didactic intervention. The study underlines the effectiveness of targeted educational interventions in marine sciences, suggesting that non-formal educational settings influence student outcomes more than family or informal sources. Younger students appeared more adaptable and responsive to educational stimuli. The study advocates for refined educational strategies integrating cognitive and emotional elements, emphasizing real nature experience.

1. Introduction

The ocean, covering over 70 % of the Earth's surface and containing 97 % of its water, stands as the planet's most prominent physical characteristic (Kennish, 2000). The ocean regulates weather and climate, is a major source of atmospheric oxygen, and hosts a great diversity of life and ecosystems; it supports economies in countries worldwide and is essential to human health and welfare (e.g., Cava et al., 2005; Whitmee et al., 2015; Fleming et al., 2019; IPCC, 2019). However, the ocean is under threat. Human activities pose serious dangers to the "health" of the ocean, and, thereby, to humans' health and welfare. Coastal zone destruction, overfishing, marine pollution, hypoxic dead zones, ocean acidification, sea-level rise, coastal flooding and an increased frequency and intensity of extreme storms have been documented in numerous studies (Fleming et al., 2019).

The responsibility to restore the health of the ocean for our own benefit, our children's, and that of future generations has been emphasized repeatedly. Consistent with these goals, several global initiatives have been established. Notably, the United Nations declared the Decade of Ocean Science for Sustainable Development (2021–2030), aiming to halt the deterioration of ocean health and unite ocean stakeholders globally under a unified strategy. This initiative seeks to enable ocean science to provide comprehensive support to nations in fostering conditions conducive to the ocean's sustainable development (UNESCO-IOC, 2021). The Decade has three objectives, each with its sub-objectives; a sub-objective of the third Objective is the promotion of formal and informal education, including Ocean Literacy (UNESCO-IOC, 2021).

The Ocean Literacy movement is a broad effort by scientists and educators that began in the US in 2002 to include Ocean Science in school curricula (NOAA, 2013). The knowledge that citizens must acquire by the end of high school (Grade 12) in the U.S. has been determined (Schoedinger et al., 2010) and the "Ocean Literacy Framework" was developed. This Framework includes the "Ocean Literacy Guide" and the "Ocean Literacy Scope and Sequence for Grades K–12" (NMEA, 2010; NOAA, 2013). The Guide describes the definitions of Ocean

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https://doi.org/10.1016/j.marpolbul.2024.116297
Received 11 February 2024; Received in revised form 23 March 2024; Accepted 23 March 2024

Literacy ('an understanding of the ocean's influence on you and your influence on the ocean') and the ocean literate person ('a person who understands the essential principles and fundamental concepts, can communicate about the ocean in a meaningful way, and is able to make informed and responsible decisions regarding the ocean and its resources'). It also outlines the 7 Essential Principles and 45 Fundamental Concepts of Ocean Literacy that all US students should understand by the end of high school (Grade 12, NOAA, 2013). The seven Essential Principles of Ocean Literacy are given in Table 1. The "Ocean Literacy Scope and Sequence for Grades K–12" provides educators with guidance on what students should understand in the elementary and secondary school grades (NMEA, 2010).

Ocean Literacy has now transcended the borders of the US and has been accepted worldwide. In particular, new professional organizations and networks have been developed to promote Ocean Literacy, similar to the U.S. National Marine Educators Association (Fauville et al., 2019). In addition, efforts have been made to regionally adapt and thematically specialize the Essential Principles and Fundamental Concepts of Ocean Literacy (Great Lakes Literacy, Fortner and Manzo, 2011; Mediterranean Sea Literacy, Mokos et al., 2020a; Estuarine Principles and Concepts, NOAA, 2019; Principles and Concepts about Seagrasses, Apostoloumi et al., 2021). Some countries, such as Portugal, adopted the Principles of Ocean Literacy and developed new approaches tailored to their specific contexts (Costa and Caldeira, 2018). Also, museums, aquaria and science centers have restructured their programs, exhibits, and activities to incorporate the Ocean Literacy guidelines (Schubel and Schubel, 2008; Thompson et al., 2016).

Scientific research on Ocean Literacy has been extensively developed (see Costa and Caldeira, 2018; Paredes-Coral et al., 2021; Cavas et al., 2023 for reviews). A significant part of the relevant literature focuses on assessing the level of Ocean Literacy, or its individual dimensions, among different groups in different countries (see for review Costa and Caldeira, 2018; Cavas et al., 2023). Specifically, studies examined the level of Ocean Literacy, or its dimensions among primary and secondary school students (Guest et al., 2015; Mogias et al., 2019; Realdon et al., 2019; Fauville et al., 2019; Tsai and Chang, 2019; Tsai et al., 2019; Lin et al., 2020; Aboulail and Tajuddin Ahmad, 2021), as well as university students (McCrossan and Molloy, 2019) and the general public (e.g., Steel et al., 2005). In addition, research had assessed the knowledge, attitudes, perceptions and/or environmental behaviors of various groups (e.g., primary and secondary school students, university students, coastal residents) on specific marine environmental issues and problems, such as marine organisms and ecosystems, marine litter, and seawater desalination (Kim et al., 2013; Heck et al., 2016, 2018; Hartley et al., 2015, 2018; Sigit et al., 2020; Andriopoulou et al., 2022).

In addition, Ocean Literacy education programs and learning activities have been developed and investigated through interventional studies, showing students' knowledge enhancement, particularly after hands-on activities (e.g. Cummins and Snively, 2000; Lambert, 2005; Lambert, 2006; Stepath, 2007; Plankis and Marrero, 2010; Hartley et al., 2015, 2018; Barracosa et al., 2019; Mokos et al., 2020b; Cavas et al., 2023). Notably, coastal lagoons, vital coastal systems of significant ecological and socioeconomic importance (e.g., Pérez-Ruzafa et al., 2020), have been the focus of a number of such educational programs (e.g., Cheng et al., 2008; Akwetey and Abrokwah, 2023). For instance, the Lagoon Quest program was designed to enhance students' knowledge of estuarine ecology and watershed concerns specific to the Indian River Lagoon (Cheng et al., 2008). It featured twelve classroom activities before and after a field trip, along with a one-day excursion during which students gathered data on water quality and collected organisms from the lagoon; additionally, a teacher guide and student lab book were developed, outlining in-class activities and providing study trip tips (Cheng et al., 2008).

A significant portion of the scientific literature on Ocean Literacy focuses on its promotion in Greece (see Costa and Caldeira, 2018; Cavas et al., 2023), a country distinguished by its extensive coastline, approximately 50 coastal lagoons, and numerous islands. In Greece, the sea is not only a major economic asset but also a source of recreation, inspiration, and a crucial part of Greek cultural heritage. Coastal lagoons are predominantly utilized for extensive fish farming, with the most significant ones being protected under the Ramsar Convention or included in the Natura 2000 network (Nicolaidou et al., 2005).

Several studies have focused on assessing the level of Ocean Literacy among primary and secondary school students and pre-service teachers in Greece, indicating, generally, a low to moderate knowledge of ocean science issues and positive attitudes towards ocean stewardship (Boubonari et al., 2013; Mogias et al., 2015; Markos et al., 2017; Mogias et al., 2019; Cheimonopoulou et al., 2022; Koulouri et al., 2022). The presence of ocean science topics in Greek primary and secondary school textbooks has also been analyzed, revealing limited and fragmented information (Mogias et al., 2021, 2022; Stasinakis, 2021). These findings, which are generally consistent with those from studies in different regions and countries (e.g., Ballantyne, 2004; Guest et al., 2015; Hartley et al., 2018; Mogias et al., 2019; Realdon et al., 2019), highlight the need to promote Ocean Literacy in Greece. In this vein, a sea-turtle conservation educational module for Greek primary school students has been implemented, and its cognitive and attitudinal effects evaluated (Dimopoulos et al., 2008). Furthermore, the impact of a teaching intervention on primary school students' understanding of ocean acidification has been investigated (Boubonari et al., 2023). In addition, a didactic intervention focused on digital storytelling and experiential hands-on activities covering concepts of marine pollution confirmed the importance of digital storytelling for students' ocean literacy enhancement (Andriopoulou et al., 2022).

Recently in Greece, a project titled "Engaging Primary and Secondary School Students in Marine Sciences" was developed, supervised by the first author of this article. Its goal was to develop students' knowledge about and attitudes towards about the marine environment, so as they are potentially capable of using it in order to produce innovative and effective solutions for future marine environmental protection. The core idea of the project was to transform existing educational settings, such as environmental education centers, science laboratory centers, and university environmental education laboratories, into centers of engagement for students in ocean literacy-focused programs (blue hubs). This project was conducted under the Action 'Science and Society - Research, Innovation, and Dissemination Hubs' of the Hellenic Foundation for Research and Innovation. A specific objective of this project involved designing and implementing an educational intervention. This intervention aimed to enhance the knowledge of Greek primary and secondary school students about the abiotic and biotic characteristics of coastal lagoons and the interconnection between coastal lagoons and human activities. Additionally, it sought to improve students' attitudes

Table 1
The seven Essential Principles of Ocean Literacy (NOAA 2013).

The Earth has one big ocean with many features.
The ocean and life in the ocean shape the features of Earth.
The ocean is a major influence on weather and climate.
The ocean made the Earth habitable.
The ocean supports a great diversity of life and ecosystems.
The ocean and humans are inextricably interconnected.
The ocean is largely unexplored.

towards the marine environment.

The primary objective of this study was to contribute to the conservation and sustainable use of seas and marine resources by promoting Ocean Literacy. Specifically, it aimed to evaluate the impact of an educational intervention, based on first-hand experiences, on: (1) Greek primary and secondary school students' knowledge of coastal lagoons' abiotic and biotic characteristics, as well as their interconnection with humans, and (2) their attitudes towards the marine environment and its conservation. Furthermore, the study explored the effects of students' grade level and their parents' educational background on the effectiveness of the educational intervention.

The study was guided by the following research questions:

1. To what extent does a targeted educational intervention effectively enhance Greek public school students' understanding of the abiotic and biotic characteristics of coastal lagoons and their interconnection with humans?
2. How does the educational intervention influence Greek public school students' attitudes towards marine ecosystems and their conservation?

The knowledge gained by students about this specific area, and the attitudes they potentially develop, could evolve into competencies for the modern citizen, enabling them to contribute to the protection of the marine environment. Evaluating the educational intervention may lead to its refinement; subsequently, the enhanced intervention could be more broadly implemented in formal and non-formal educational settings in Greece. In addition, after adapting to the local and regional particularities of coastal lagoon ecosystems, it could be applied in educational settings of other countries.

2. Coastal lagoons: abiotic and biotic characteristics, value, threats and protection

Coastal lagoons are a prevalent type of coastal environment, accounting for 13 % of coastal areas globally (Barnes, 1980, as cited in Pérez-Ruzafa et al., 2020). Coastal lagoons are dynamic systems characterized by significant environmental variability (Pérez-Ruzafa et al., 2019). Environmental conditions differ among lagoons, within different areas of the same lagoon, seasonally, and even daily (Pérez-Ruzafa et al., 2019 and the references cited therein).

Coastal lagoons are characterized by high levels of primary production, which in turn support rich faunal communities (Kennish, 2016, as cited in Pérez-Ruzafa et al., 2019). The organisms within coastal lagoon ecosystems are well-adapted to the environmental variability typical of these ecosystems (e.g., Kevrekidis, 2004; Pérez-Ruzafa et al., 2019 and the references cited therein). Coastal lagoons harbor high biodiversity, providing a variety of habitat types for many organisms. They function as refugia, feeding grounds, and nursery areas for numerous marine species and autochthonous or migratory bird species (Pérez-Ruzafa et al., 2020 and the references cited therein).

They, also, offer a wealth of ecosystem services, as well as societal goods and benefits, crucial for human well-being. Specifically, they provide high-value environmental services and act as reservoirs of genetic diversity, sheltering a significant portion of the world's biodiversity (see review in Pérez-Ruzafa et al., 2019). Humans benefit from the high biological productivity of these lagoon systems, which often support fisheries, aquaculture, and shellfish harvesting (e.g., Newton et al., 2014; Pérez-Ruzafa et al., 2019).

Moreover, coastal lagoons hold great educational value, being areas of natural beauty that attract school-aged children and create favorable conditions for learning. The coastal lagoon environment, easily accessible and marked by rich biodiversity, is ideal for students to grasp basic ecosystem principles, the impact of human activities on the natural environment, and the need for its protection.

Legislation and policies aim to protect coastal lagoons. Notably, many are safeguarded under the Ramsar Convention on Wetlands, and in Europe, many form part of the Natura 2000 network (Pérez-Ruzafa et al., 2020). However, coastal lagoons are frequently subject to intense anthropogenic pressures and impacts. They are among the most endangered ecosystems, with eutrophication being the primary threat (e.g., Newton et al., 2014; Pérez-Ruzafa et al., 2019; Kevrekidis et al., 2023). This situation underscores the need for developing and implementing effective legislation, policies, and management plans for coastal lagoons. Educating the public about their value, along with increased awareness, can enhance the protection of these vital ecosystems and help ensure their sustainable future.

3. Materials and methods

3.1. Participants

The study involved a total of 79 students from Greek public schools, selected through convenience sampling based on the first author's connections with the school administrations. The gender distribution was nearly even, with 51 % male and 49 % female participants. In terms of grade levels, 48 % were in the last two grades of primary education, specifically ages 11–12 years, while the remaining 52 % attended high school.A survey of the parents' educational backgrounds revealed that 60 % of the fathers had university qualifications. In contrast, 33 % completed high school, and 8 % had middle school education. Among the mothers, 77 % held university qualifications, 20 % had completed high school, and a combined 2.5 % had either primary or middle school education.

3.2. Educational intervention

An educational resource titled "Exploring the Coastal Lagoons" was developed to facilitate the educational intervention, adhering to the guidelines for creating coherent and comprehensive environmental education materials (North American Association for Environmental Education, NAAEE, 2021). This resource comprises a section introducing teachers to coastal lagoons' ecosystems, values, threats, and protection, and a section for student activities featuring photos, sketches, videos, bird sounds, and web searches.

The educational intervention was conducted solely by three of the authors, who are marine sciences' educators and had served as teachers either in primary or secondary education. Classroom teachers were present during the sessions, but they were not involved and were asked not to answer questions and/or clarify possible misunderstandings between the sessions. The educational intervention was structured into three distinct sessions, each customized for different grade levels and comprised of structured, inquiry-based activities. Inquiry is considered an active form of teaching, engaging students in answering research questions using data, providing them with knowledge via investigation, rather than receiving it directly from educators (NRC, 1996; Jerrim et al., 2019).Thus, the activities throughout the three sessions involved students in answering questions, in planning and conducting field investigations, using appropriate tools and techniques to gather and study data.

First Session: Classroom-based inquiry into coastal lagoon ecosystem. During this initial two-hours session, held in the classroom, students, using the specialized educational guide, were asked to define coastal lagoons. In addition, students studied key environmental parameters—such as water depth, turbidity, temperature, salinity, and dissolved oxygen—using online data from national meteorological services, as well as their impact on the composition of biotic communities. Additionally, students examined the biodiversity of coastal lagoons, focusing on characteristic seaweed, angiosperm, macroinvertebrate, fish, and bird species, and studied the coastal lagoon food web. The session concluded with a video presentation on scientific sampling methodologies relevant to coastal lagoon research. Students were also introduced to the specific equipment used in these sampling techniques, completed with a detailed tutorial on its operation, so as to direct their attention towards the relevant aspects of the tasks, when being on field.

Second Session: Field trip and sampling at a coastal lagoon. The subsequent session was a four-hours field trip to a coastal lagoon. Students, divided into sub-groups of 4–5, equipped with necessary field gear, engaged in hands-on exploration. They measured water physicochemical parameters and collected samples of macrophytes and zoobenthos using standard scientific equipment. Each sub-group completed a field sampling form to record their observations. The collected samples were preserved for further analysis in the third session. Additionally, the students conducted bird observations using binoculars and telescopes, aided by a pocket bird guide for initial species identification, with their observations systematically noted on dedicated forms.

Third Session: Laboratory analysis and discussion on coastal lagoons' conservation. The final four-hours session took place in a biology laboratory (blue hub). It began with a recap of the first session and fieldwork activities, setting the stage for an in-depth discussion about the value of coastal lagoons, their ecosystem services, threats, and potential conservation measures. The macrophyte and macroinvertebrate samples previously collected were then subjected to basic taxonomic sorting, followed by preliminary species identification under stereoscopes. Visual aids, such as a continuous on-screen display of characteristic coastal lagoon organisms, assisted the students in this task. Each sub-group documented their findings on a laboratory worksheet, listing the scientific and/or common names and the abundance of the identified organisms. The session concluded with a comprehensive discussion that synthesized the empirical data and its wider implications.

3.3. Instrumentation

To obtain a comprehensive understanding of participants' demographic profiles and knowledge base, various pen-and-pencil questionnaires were employed both before and after the intervention. Demographic data were collected through a questionnaire detailing participants' gender, grade level, and their parents' education. Participants were also asked to assess the extent to which various information sources, both formal and informal, contribute to their information about coastal lagoons. They rated each source on a four-points scale ranging from "1 = Not at all" to "4 = Very much." To assess students' understanding of coastal lagoons and associated concepts, a knowledge questionnaire comprising 17 multiple-choice questions was administered. These questions encompassed topics ranging from basic abiotic coastal lagoon characteristics to more complex subjects like environmental challenges faced by coastal lagoon organisms. The 17 items in the knowledge questionnaire were scored using a binary scale: 0 denoting an incorrect response and 1 indicating a correct answer. Additionally, an attitudes questionnaire was employed to ascertain participants' sentiments and perspectives towards the marine environment. This instrument presented a series of eight statements related to the marine environment and its conservation, with participants indicating their agreement using a five-point Likert scale, ranging from "1 = Strongly Disagree" to "5 = Strongly Agree". The detailed instruments used in this study can be found in Appendix A.

3.4. Data analysis

Several statistical techniques were used to evaluate the educational intervention's effectiveness on participants' knowledge and attitudes towards marine conservation. Descriptive statistics summarized the data on knowledge and attitudes before and after the intervention. To evaluate whether the knowledge questionnaire measures a unified construct, Confirmatory Factor Analysis (CFA) was carried out with the lavaan package in R (Rosseel, 2012). The analysis incorporated tetrachoric correlations for estimating the latent trait that binary response items aim to capture, with the goal of having all knowledge items load onto a singular latent construct. For reliability assessment, Cronbach's alpha was calculated to evaluate the internal consistency of the knowledge and the attitudes questionnaires, with an additional calculation of ordinal alpha (Zumbo et al., 2007) for the knowledge items to take into account their ordinal nature. To determine the construct validity of the attitudes questionnaire, Exploratory Factor Analysis (EFA) paired with parallel analysis was employed. This method helped identify the number of factors representing the underlying structure of the attitudes questionnaire, expected to reveal a single-factor solution indicative of a cohesive construct. EFA was selected over CFA due to the less definitive understanding of the factor structure in contrast to the knowledge scale, where the structure was more clearly hypothesized. Linear mixed-effects models, facilitated by the lme4 package in R(Bates et al., 2015), analyzed the change in total knowledge scores and mean attitude scores, incorporating pre- and post-intervention as fixed effects along with student grade level and parental education levels. A random intercept for each student addressed the repeated measures design. The analysis thoroughly evaluated the model's assumptions, including linearity, independence (via random effects), homoscedasticity, and normal distribution of residuals and random effects, ensuring the validity of the findings.

4. Results

4.1. Reliability and validity in knowledge and attitude measurements

In assessing the construct validity of the knowledge scale, the CFA model showed acceptable fit($\chi^2(119) = 135.524$, p-value of 0.143, RMSE = 0.042, 90%CI[0.000, 0.073], CFI = 0.941, TLI = 0.932), indicating that all 17 knowledge items loaded onto a single construct. Reliability of the knowledge construct was evaluated using Cronbach's alpha, which produced a value of $\alpha = 0.789$. However, considering the ordinal nature of the indicators, the ordinal alpha (as proposed by Zumbo et al., 2007) was also calculated, yielding a higher value of $\alpha_{\text{ord}} = 0.881$. This suggests that when the ordinal nature of the data is taken into account, the reliability of the construct is even more robust. Subsequently, a total knowledge score was computed by summing the points for each student.

For the attitudes questionnaire, Cronbach's alpha values surpassed 0.8 both pre- and post-intervention, indicating excellent internal consistency. EFA identified a one-factor solution, underscoring the notion that the attitude items represent a single construct or dimension. This conclusion was reinforced by the substantial factor loadings of each item on this main factor. Moreover, the item-total correlations, consistently exceeding 0.30 across all items, provided insight into the individual contributions of each item to the collective construct, underscoring their pivotal role in the measurement system. The answers to the eight questions assessing attitudes towards marine environments were averaged to derive an average attitude score for every student.

4.2. Understanding coastal lagoons: knowledge of abiotic and biotic characteristics and human interactions

In our survey assessing knowledge about coastal lagoons, we found notable variations in respondent understanding. As shown in Table 2, prior to the educational intervention, approximately 79.7 % accurately described basic abiotic characteristics of a coastal lagoon, and 77.2 % correctly identified its typical water type, based on salinity level, as brackish. However, more intricate aspects, like the predominant category of non-microscopic animals, in terms of number of individuals, in a coastal lagoon, were less understood, with only 24.0 % correctly identifying invertebrates. The implications of human activity on coastal lagoons were better recognized, with 74.7 % and 67.1 % of respondents correctly pointing out detrimental activities and potential protective measures, respectively. However, understanding issues related to coastal lagoon organisms, like the habitat preferences of benthic

Table 2
Comparative Knowledge Assessment on coastal lagoons' abiotic and biotic characteristics, and the coastal lagoon-human interconnection: Pre- and Post-Educational Intervention Results

Question	Percentage Correct	
	Pre	Post
1. A coastal lagoon is a body of water that: a. has a very great depth and is located near the sea. b. has a shallow depth and is very close to the sea or directly communicates with it. c. has a shallow depth and is far from the sea. d. I don't know.	79.7%	98.7%
2. The water of the coastal lagoon is usually: a. fresh b. brackish c. salty d. I don't know.	77.2%	93.5%
3. The salinity of the coastal lagoon: a. is higher in the summer than in the winter. b. is higher in the winter than in the summer. c. remains stable throughout winter and summer. d. I don't know.	50.6%	74.0%
4. The water temperature: a. of the sea changes more easily than that of the coastal lagoon. b. of both the coastal lagoon and the sea remains more or less always stable. c. of the coastal lagoon changes more easily than that of the sea. d. I don't know.	37.9%	63.6%
5. The turbidity of the coastal lagoon's water depends on: a. the salinity of the water. b. the presence of fish swimming in the water. c. the amount of suspended material and microscopic organisms floating in the water. d. I don't know.	37.9%	29.9%
6. Which of the following categories of organisms has the highest number of individuals in a coastal lagoon? a. fish b. invertebrate animals c. birds d. I don't know.	24.0%	66.2%
7. Coastal lagoon organisms must cope with continuous changes in environmental factors such as... a. temperature b. salinity c. both a and b d. I don't know.	69.6%	79.7%
8. Seagrasses are: a. flowering plants with roots, stems, and leaves found at great depths in the sea. b. flowering plants with roots, stems, and leaves found in shallow areas of the sea. c. algae found in both deep and shallow parts of the sea. d. I don't know.	27.8%	39.7%
9. The benthic invertebrates of the coastal lagoon: a. live on or within the lagoon's bottom and can withstand large changes in water salinity and temperature. b. live on or within the lagoon's bottom and are very vulnerable to changes in water salinity and temperature due to their small size. c. swim in the lagoon's water and are very vulnerable to changes in salinity and temperature due to their small size. d. I don't know.	21.5%	29.1%
10. Seagrasses need the energy from the sun to produce their food. a. correct b. incorrect c. I don't know	69.6%	79.7%
11. _______ are organisms that feed on plants or animals. a. Consumers b. Producers c. I don't know.	69.6%	81.0%
12. Which organism is a producer? a. the shrimp b. the fish c. the seagrass d. I don't know	49.4%	68.3%
13. The birds one encounters in the coastal lagoon and the surrounding area: a. are birds that live permanently in the lagoon b. are migratory birds that stay for a specific season in the lagoon, depending on the species c. are seagulls d. all of the above e. I don't know	40.5%	55.7%
14. Pollution in the coastal lagoon arises from... : a. fertilizers from rivers and surrounding fields b. oil leakage from boats c. both a and b d. I don't know	53.2%	72.1%
15. Which of the following should not be done in a coastal lagoon? a. boating b. bird watching c. entry of fertilizers from the surrounding fields d. I don't know	74.7%	83.5%
16. The biggest problem with the cut nets left in the coastal lagoon is that... a. they catch fish b. they change the quality of the water c. they trap animals d. I don't know	63.3%	67.1%
17. How can the coastal lagoon be protected? a. through public awareness and sensitization b. through protective measures by the state c. both a and b d. I don't know	67.1%	74.7%

invertebrates and their ability to tolerate environmental variability (21.5 %) revealed areas where knowledge can be further enhanced. The overall distribution of correct answers per respondent exhibited a bell-shaped pattern, with the majority of respondents achieving between 7 and 9 correct responses. This suggests that most participants had a low to moderate level of knowledge about Marine Science issues prior to the intervention.

Following the educational intervention, the survey results indicated a marked improvement in certain areas of understanding about coastal lagoons. Notably, participants' comprehension of basic abiotic characteristics of a coastal lagoon surged to 98.7 %, and 93.5 % correctly identified the typical water type of a coastal lagoon as brackish. The understanding of the environmental variability faced by coastal lagoon organisms also improved, with 79.7 % of students correctly identifying the variability in abiotic characteristics such as water temperature and salinity that these organisms have to cope with. However, certain areas still posed challenges for many students. For instance, only 29.1 % of students demonstrated a clear understanding of benthic invertebrates' habitat preferences. Additionally, while a considerable portion of students recognized salinity variability in coastal lagoons, the type of seasonal variation in salinity (i.e., salinity being higher in the summer than in the winter) was identified correctly by 74.0 % of the respondents. Post-intervention results also highlighted an increased awareness regarding human activities and their impacts on coastal lagoons. A significant 83.5 % of students were cognizant of activities that shouldn't be done in a coastal lagoon, underscoring their understanding of potential detrimental actions. Furthermore, 74.7 % of respondents recognized both public awareness campaigns and state protective measures as viable strategies to protect coastal lagoons, showcasing the intervention's effectiveness in conveying the importance of collaborative efforts in conservation.

Concerning the first research question, a mixed-effects model revealed that the educational intervention had a pronounced and significant impact on students' knowledge (Table 3). Specifically, knowledge scores after intervention were, on average, higher than those documented before the intervention (11.46 vs 9.14). This difference amounted to approximately 2.32 units, a statistically significant shift ($t = -4.995$, $p < 0.05$). When considering the grade level of participants, primary school students exhibited knowledge scores that were, on average, 0.79 units lower than those of high school students. However, this observed difference did not reach statistical significance ($t = -1.323$). Parental educational background, represented separately by both fathers' and mothers' education levels, appeared to associate positively with students' knowledge scores. For fathers, every unit increase in educational level corresponded with a 0.78 unit increase in the knowledge score of the student ($t = 1.605$). Similarly, for mothers, each unit increase in education was linked to a 0.83 unit increase in the student's knowledge score ($t = 1.492$). It's worth noting that while these trends hint at a positive influence of parental education on student knowledge, they did not achieve strong statistical significance in our model. In summary, the educational intervention appears to be effective in enhancing students' knowledge regarding coastal lagoons' abiotic and biotic characteristics, and the coastal lagoon-human interconnection. While there are indications that grade level and parental education might play roles in determining this knowledge, their effects, within the context of this study, were not robustly significant.

4.3. Sources of students' knowledge on coastal lagoons

Students primarily sourced their knowledge about coastal lagoons from environmental education school programmes, with school courses being another significant contributor, highlighting the role of formal

Table 3
Results of the mixed-effects model for knowledge scores

Predictor	Estimate	Standard Error	t-value
Intercept	5.99	2.39	2.504
Measure (Before vs. After)	-2.32	0.46	-4.995
Grade (Primary vs. High)	-0.79	0.59	-1.323
Father's Education	0.78	0.48	1.605
Mother's Education	0.83	0.56	1.492

Note. Random Effects: Subject (Intercept): Variance = 2.55, Std. Dev. = 1.59, Residual: Variance = 8.49, Std. Dev. = 2.91

education (Table 4). Informal sources such as friends and family and social media played a moderate role in shaping perceptions. Traditional media, including TV and radio, and newspapers and magazines, had a lesser influence. Overall, formal education and modern platforms were considered more important in shaping students' understanding of coastal lagoons.

4.4. Attitudes towards the marine environment

The mean attitude scores, which are on a scale from 1 (Strongly disagree) to 5 (Strongly agree), suggest that participants generally have positive attitudes towards the marine environment, its protection, and their role in it (Table 5). Notably, the item related to pursuing a profession that contributes to the protection of the sea had a lower mean score compared to the others, indicating that while students recognize the importance of the marine environment, they might not necessarily see themselves pursuing a career in its protection.

Following the educational intervention, an increase in positive attitudes towards marine environments was observed. A mixed-effects model revealed that the attitudes after intervention were, on average, higher than before intervention, with an increase of approximately 0.14 units, although this shift was not statistically significant ($t = 1.339$, Table 6). Considering grade levels, primary school students demonstrated, on average, attitudes that were 0.21 units more positive than those of high school students. This observed difference was marginally insignificant, with a t-value of 1.85. In terms of parental education's influence on students' attitudes, the model did not uncover strong effects. Specifically, fathers' education level showed a slight decrease in attitude scores by 0.02 units for every unit increase in educational level, but this was not significant ($t = -0.249$). Similarly, mothers' education level was associated with a minor increase in attitude scores by 0.06 units for every unit increase in educational level, but again, this was not statistically significant ($t = 0.56$).

In conclusion, addressing research question 2, the educational intervention appears to have exerted a modest positive influence on students' attitudes towards the marine environment. However, the effect's robustness needs further investigation. Grade levels indicated some effect, with primary school students appearing to have slightly more positive attitudes than high school students after intervention. Parents' educational backgrounds, on the other hand, did not show a significant influence on students' attitudes in this study.

5. Discussion

This study evaluated the effectiveness of an educational program in enhancing Greek public school students' knowledge about coastal lagoons, their abiotic and biotic characteristics, and the interconnection between coastal lagoons and humans, as well as in improving their attitudes towards the marine environment, using structured inquiry-based activities in the classroom, field and laboratory. The knowledge survey results shed light on the students' understanding both before and after the intervention. Before the intervention, students demonstrated a strong grasp of the basic abiotic characteristics of coastal lagoons, but

Table 4
Contribution of various information sources on students' information about coastal lagoons (1=Not at All, 4 = Very much)

Sources	Mean	SD
Environmental education school programmes	3.10	0.83
School courses	2.87	1.43
Social media	2.48	1.21
Friends and family	2.48	1.44
Electronic press	2.33	1.28
NGOs	2.00	1.22
TV, Radio	1.76	1.14
Newspapers, magazines	1.62	0.97

Table 5
Students' attitudes towards the marine Environment and its conservation: Pre- and post-intervention assessment

	Mean (SD)	
Question	Pre	Post
1. I am interested to know that marine animals live in a healthy marine environment.	3.96 (1.06)	4.13 (0.69)
2. I am interested in learning about the marine environment.	3.67 (1.00)	4.00 (0.78)
3. Humans cannot live without the sea.	4.10 (1.10)	4.05 (1.18)
4. People do not have the right to alter the coasts and interfere with coastal ecosystems.	3.71 (1.23)	3.73 (1.12)
5. It is important for a young person like me to contribute to the protection of the marine environment.	3.80 (1.09)	4.16 (0.69)
6. When I grow up, I want to pursue a profession that contributes to the protection of the sea.	2.63 (1.23)	2.44 (1.01)
7. I want to learn what I can do to protect a coastal lagoon.	3.67 (0.94)	3.96 (0.94)
I am interested in participating in the cleanup of a lagoon's coast.	3.87 (1.15)	4.05 (0.80)
Total	3.69 (0.81)	3.83 (0.52)

Table 6
Results of the mixed-effects model for attitude scores.

Predictor	Estimate	Standard Error	t-value
Intercept	3.43	0.47	7.349
Measure (Before vs. After)	0.14	0.10	1.339
Grade (Primary vs. High)	0.21	0.11	1.848
Father's Education	-0.02	0.09	-0.249
Mother's Education	0.06	0.11	0.560

Note. Random Effects: Subject (Intercept): Variance = 0.047, Std. Dev. = 0.22 Residual: Variance = 0.42, Std. Dev. = 0.65

they were less informed about coastal lagoon organisms. This finding aligns with a larger-sample study indicating that Greek primary school students aged 8 to 11 years have a moderate level of knowledge about marine sciences issues (Mogias et al., 2019), as well as with other similar studies concerning Greek secondary students (e.g. Cheimonopoulou et al., 2022; Koulouri et al., 2022). Moreover, this knowledge level among primary and secondary students regarding marine sciences seems to be a common trend in various countries and regions, as revealed by several studies (e.g., Cummins and Snively, 2000; Ballantyne, 2004; Plankis and Marrero, 2010; Guest et al., 2015; Mogias et al., 2019; Lin et al., 2020; Mokos et al., 2020b).

Interestingly, the students of the present study reported that their primary sources of knowledge about coastal lagoons were environmental education school programs and school courses, while in other studies internet appears to be the main information source regarding marine sciences issues (e.g. Mogias et al., 2015; Koulouri et al., 2022). This result, along with their moderate knowledge, suggests a lack of comprehensive implementation of marine sciences topics in the Greek curriculum. Given that Greek primary and secondary education primarily relies on textbook-based teaching, this conclusion is supported by the observation that primary and secondary science textbooks offer limited and fragmented information on these sciences (Mogias et al., 2021, 2022; Stasinakis, 2021).

Our findings suggest that comprehensive educational interventions, encompassing classroom-based inquiry into coastal ecosystems, fieldwork involving observations, measurements, and sample collection, as well as rough organism identification in a biology laboratory setting, followed by thorough discussions on marine environment-human interconnections, can significantly enhance students' knowledge of coastal ecosystems, their value, and conservation. The positive impact of educational interventions on primary and secondary school students' understanding of marine-related topics, using classroom and field-trip experience, as well as laboratory work, aligns with findings from previous relative studies (e.g. Cheng et al., 2008; Dimopoulos et al., 2008; Barracosa et al., 2019; Andriopoulou et al., 2022; Akwetey and Abrokwah, 2023). A positive impact has been also highlighted in previous studies which generally applied hands-on experiences (e.g., Fortner and Teates, 1980; Fortner, 1985; Cummins and Snively, 2000; Lambert, 2005; Stepath, 2007; Plankis and Marrero, 2010; Hartley et al., 2015, 2018; Mokos et al., 2020b). The present study, also, supports that this type of education not only enhances knowledge and positive attitudes about the environment, but it also develops skills in science (Cheng et al., 2008; Barracosa et al., 2019; Andriopoulou et al., 2022).

Moreover, the present study highlights the fact that an important component of the effectiveness of these interventions is the creation of educational materials which provide information about the scientific background, the field excursion and sampling, as well as the laboratory protocols (Barracosa et al., 2019). Particularly, the observed significant improvement in students' comprehension across various topics highlights the effectiveness of the educational material "Exploring the Coastal Lagoons," designed for this study, in enhancing primary and secondary school students' knowledge of coastal lagoons' abiotic characteristics, biodiversity, and the interdependence between coastal lagoons and humans. Overall, this increase in understanding endorses the efficacy of the educational approach used.

According to the findings of the post-test, although the intervention was generally beneficial, not all topics experienced equal gains. Understanding of certain aspects, like the factors affecting water turbidity, showed even a slight decline in comprehension after the intervention. This probably indicates that this concept is of high difficulty for both elementary and secondary students, probably because of its complex nature. Indeed, Araújo et al. (2022) also found that although middle school students' knowledge about coastal water physic-chemical parameters, including turbidity, rose immediately after a science project, in the retention test, taken after a year, students scored low on the questions concerning the concept of turbidity. In addition, the difficulty for the concept of turbidity could be attributed to the fact that turbidity is caused by suspended material which is not evident to the unassisted eye, and children's knowledge seems firmly anchored in things they can directly see (Ero-Tolliver et al., 2013). As for the item concerning the habitat preferences of benthic invertebrates in coastal lagoons, the students showed unexpectedly minimal improvement, although the specific topic was the main subject during sampling in the field and in the laboratory work. This fact could imply that the answers of the specific item, which involved two different characteristics of the habitat, probably confused the students, thus, this item should be revised.

Our analysis of attitudes towards the marine environment illuminated students' perceptions and the intervention's potential for transformative effects. Prior to the intervention, students generally held positive attitudes, which likely form a solid foundation for fostering Ocean Literacy, as also observed by Guest et al. (2015). Similar concerns and positive attitudes have been consistently observed among primary and secondary school students from diverse cultural backgrounds in various studies such as Ballantyne (2004), Kim et al. (2013), Guest et al. (2015), Hartley et al. (2015), and Mokos et al. (2020b).

Interestingly, the survey item about pursuing a career in marine protection scored lower than others, indicating that while students recognize the marine environment's importance, they may not envision themselves in careers related to its protection. This lack of interest in marine professions might reflect the students' specific career aspirations and future dreams, as suggested by Guest et al. (2015). Children's perceptions of certain jobs and careers are often formed at a young age and can be influenced by factors such as gender stereotypes, socio-economic background, and the people they know (Chambers et al., 2018).

The educational intervention appeared to have a modestly positive effect on students' attitudes towards the sea, supporting the notion that programs incorporating direct nature experiences can strengthen attitudes towards marine environments. However, the impact was not robustly significant. Several factors may account for this. One possibility is that students' pre-existing positive views on marine conservation limited the potential for significant attitude shifts. This is consistent with findings that significant improvements in attitudes post-intervention are usually observed where initial positive attitudes are low (Dimopoulos et al., 2008; Mokos et al., 2020b). The intervention's duration or focus might have been insufficient for deeply affecting emotional or value-driven aspects crucial for shaping attitudes. Repeated exposure to environmental education, such as experiencing nature over several days, could have a stronger positive impact on students' attitudes. The duration, frequency, and setting of nature encounters have been reported as critical factors for the success of environmental education programs (Liefländer et al., 2013). Long-term tracking of attitude changes and involving students in practical conservation activities could provide deeper insights into the intervention's impact. Hands-on environmental education with direct nature experiences, like those in our intervention, is more likely to have a lasting effect on commitment to pro-environmental behavior and attitudes (Wells and Lekies, 2006).

The effects of grade level and parental education added complexity to our findings. Notably, primary school students showed slightly more positive changes in attitudes after the intervention compared to high school students. This suggests that younger students might be more adaptable and responsive to educational initiatives. Prior studies have shown that younger children frequently exhibit greater concern for environmental issues and a stronger commitment to protecting the environment (e.g., Klineberg et al., 1998; Wells and Lekies, 2006; Liefländer et al., 2013; Liefländer and Bogner, 2014). As children develop towards adolescence, their sense of independence grows, peer influence becomes more significant, and the impact of caretakers, teachers, or parents diminishes (Steinberg and Silverberg, 1986, as cited in Liefländer et al., 2013). On the other hand, the anticipated influence of parental education on students' knowledge and attitudes was not strongly evident, although previous studies have shown that parents' educational level plays a primary role in students' environmental knowledge and attitudes (Gambro and Switzky, 1994; Makki et al., 2003; Zerinou et al., 2020; Rehman et al., 2021).This could imply that the educational environment may play a more crucial role in shaping student outcomes. This observation supports the importance of continuing and expanding the implementation of the educational intervention used in this study in both formal and non-formal educational settings to promote Ocean Literacy.

6. Conclusion

In conclusion, our study underscores the critical role of specialized educational interventions in enhancing students' understanding of marine sciences and, to some extent, altering their attitudes towards the marine environment. The findings advocate for ongoing and refined educational initiatives, tailored to address specific areas of misunderstanding and appropriate for various age groups. Specifically, the results emphasize the effectiveness of the targeted educational intervention employed in this study, which encompassed classroom, fieldwork/outdoor, and laboratory activities. This approach effectively improved Greek public school students' knowledge of coastal lagoons' abiotic and biotic characteristics, and the interconnection between coastal lagoons and humans. It also moderately influenced their attitudes towards the marine environment and its preservation.

Specifically, the program successfully addressed some knowledge gaps, while other areas might necessitate more specialized teaching methods or a different instructional emphasis. For example, incorporating a relevant laboratory experiment into the intervention could enhance understanding of factors influencing water turbidity. Expanding the duration of the educational intervention, such as implementing a five-day program, could also be beneficial. This extension would allow for a more in-depth exploration of the information and activities included in the "Exploring the Coastal Lagoons" material, potentially leading to a more significant increase in students' understanding of the coastal lagoon ecosystem and its interconnection with humans.

Furthermore, the outcomes demonstrate the value of the educational material "Exploring the Coastal Lagoons" in guiding interventions aimed at these goals. Our findings also suggest that the educational context has a more substantial impact on students' knowledge and attitudes towards the marine environment than family or informal sources, and that younger students are more adaptable and responsive to educational interventions. Future educational strategies could benefit from a more extensive use of "Exploring the Coastal Lagoons," specialized teaching methods for complex concepts, and prolonged direct experiences with nature. Additionally, a balanced approach that integrates both cognitive and emotional elements would likely be advantageous. Future studies could delve deeper into the factors that enhance the success of educational interventions, ensuring our teaching methods remain both effective and engaging. Long-term tracking of changes in attitudes and engaging students in practical conservation activities would offer further insight into the lasting impact of these interventions.

The knowledge acquired by students about the coastal lagoon environment and marine sciences, along with the attitudes developed, is anticipated to evolve into competencies for the modern citizen. This would enable them to contribute to marine environment preservation through informed decision-making and responsible environmental behavior.

The next steps could involve establishing more Ocean Literacy Hubs in both formal and non-formal educational settings, such as university environmental education laboratories, environmental education centers, science laboratory centers, and wetland information centers. These hubs would possess the necessary expertise and infrastructure to carry out similar educational interventions. Additionally, expanding the scope of educational interventions to cover other vital marine ecosystems, like seagrass meadows, and broader marine sciences topics would be beneficial. Furthermore, the educational material "Exploring the Coastal Lagoons", once translated and adapted to the local and regional specifics of coastal lagoon ecosystems, could be utilized in educational settings in other countries. This initiative would be a significant step towards integrating the Principles and Concepts of Ocean Literacy and their thematic adaptations into educational practice, school curricula, and textbooks. The ultimate goal is to foster an ocean-literate society capable of making informed and responsible decisions regarding the sea and its resources.

While the study yielded valuable insights, it's important to acknowledge its limitations. The primary limitation lies in the sample size and selection method. The use of a small, convenience sample drawn primarily from Greek public schools restricts the generalizability of the findings to a wider and more diverse population. This raises concerns about the extent to which the results apply beyond the specific educational and cultural context of the study. Furthermore, as briefly mentioned previously, the study's design involved a short-term educational intervention with limited follow-up. While immediate effects on students' knowledge and attitudes were observed, the brevity of the intervention and follow-up period may not accurately reflect long-term retention or behavioral changes. Consequently, the study's ability to draw conclusions about the lasting impact of the educational program is limited. Reliance on self-reported data presents another limitation. Such data are subject to biases, as participants may respond in ways they perceive as favorable or socially acceptable, rather than providing genuine responses. This could potentially skew the findings, particularly in measuring subjective areas like attitudes and perceptions. Another limitation of the study is the fact that although it aims to enable students to contribute to the protection of the marine environment, it does not draw conclusions about students' behavior or behavioral change. Lastly, external factors such as students' prior knowledge, parental influence, and exposure to other educational experiences were not fully controlled. These factors could significantly influence students' learning and attitudes, thereby affecting the outcomes of the educational intervention.

Funding

This research was funded by the Hellenic Foundation for Research and Innovation (HFRI), 3rd Call for Action "Science and Society" "Research, Innovation and Dissemination Hubs".

CRediT authorship contribution statement

Theodoros Kevrekidis: Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Angelos Markos:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis. **Theodora Boubonari:** Methodology, Investigation. **Athanasios Mogias:** Investigation. **Paraskevi Malea:** Writing – review & editing, Writing – original draft, Visualization, Investigation. **Chrisa Apostoloumi:** Visualization, Investigation. **Alkistis Kevrekidou:** Investigation.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Acknowledgment

The authors thank the Hellenic Foundation for Research and Innovation (HFRI) for funding. We are thankful to Dimitrios Phaedon Kevrekidis, MSc for his contribution to the development of the educational material entitled "Exploring Coastal Lagoons", and A. Stamatelatou, BSc and S.C. Kyrtsidou, BSc for their support in the implementation of the educational intervention. Thanks are due to the educational staff of the Maroneia and Vistonida Environmental Education Centers, the Sciences Laboratory Center of Alexandroupolis, and the primary and secondary schools that participated in the educational program for the cooperation. Thanks are due to the anonymous referees for their thoughtful critiques and comments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2024.116297.

References

Aboulail, F.S., Tajuddin Ahmad, A.J., 2021. Ocean literacy of primary students of international schools in Riyadh, Saudi Arabia. J. Nusant. Stud. 6(2),403-423. ISSN 0127-9386 (online). Doi:10.24200/jonus.volx6iss2pp403-423.

Akwetey, M.F.A., Abrokwah, S., 2023. Environmental education toward the protection of biodiversity in a coastal lagoon in China. Limnol. Oceanogr. Bull. 32 (1), 1–3. https://www.researchgate.net/publication/368254263.

Andriopoulou, A., Giakoumi, S., Kouvarda, T., Tsabaris, C., Pavlatou, E., Scoullos, M., 2022. Digital storytelling as an educational tool for scientific, environmental and sustainable development literacy on marine litter in informal education environments (case study: Hellenic Center for Marine Research). Mediterr. Mar. Sci. 23 (2), 327–337.

Apostoloumi, C., Malea, P., Kevrekidis, T., 2021. Principles and concepts about seagrasses: towards a sustainable future for seagrass ecosystems. Mar. Pollut. Bull. 173, 112936.

Araújo, J.L., Morais, C., Paiva, J.C., 2022. Student participation in a coastal water quality citizen science project and its contribution to the conceptual and procedural learning of chemistry. Chem. Educ. Res. Pract. 23 (1), 100–112. https://doi.org/10.1039/d1rp00190f.

Ballantyne, R., 2004. Young students' conceptions of the marine environment and their role in the development of aquaria exhibits. GeoJournal 60 (2), 159–163.
Barracosa, H., de los Santos, C.B., Martins, M., Freitas, C., 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, 626. https://doi.org/10.3389/fmars.2019.00626.
Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme 4. J. Stat. Softw. 67 (1), 1–48. https://doi.org/10.18637/jss.v067.i01.
Boubonari, T., Markos, A., Kevrekidis, T., 2013. Greek pre-service teachers' knowledge, attitudes, and environmental behavior toward marine pollution. J. Environ. Educ. 44, 232–251.
Boubonari, T., Papazoglou, D.-N., Mogias, A., Kevrekidis, T., 2023. Challenging Greek primary students' knowledge of ocean acidification using the carbon cycle context. Int. J. Sci. Math. Educ. https://doi.org/10.1007/s10763-023-10431-5.
Cava, F., Schoedinger, S., Strang, C., Tuddenham, P., 2005. Science content and standards for ocean literacy: a report on ocean literacy. Retrieved from. http://coexploration.org/oceanliteracy/documents/OLit200405FinalReport.pdf.
Cavas, B., Acık, S., Koc, S., Kolac, M., 2023. Research trends and content analysis of ocean literacy studies between 2017 and 2021. Front. Mar. Sci. 10, 1200181. https://doi.org/10.3389/fmars.2023.1200181.
Chambers, N., Kashefpakdel, E.T., Rehill, J., Percy, C., 2018. Exploring the Career Aspirations of Primary School Children from around the World. Drawing the Future. Education and Employers, London, UK, p. 104.
Cheimonopoulou, M., Koulouri, P., Previati, M., Realdon, G., Mokow, M., Mogias, A., 2022. Implementation of a new research tool for evaluating Mediterranean Sea literacy (MSL) of high school students: a pilot study. Mediterr. Mar. Sci. 23 (2), 302–309. https://orcid.org/0000-0002-3418-7980.
Cheng, J.C.H., Monroe, M.C., Gordon, A., 2008. Measuring the effectiveness of lagoon quest: a case study in environmental education program evaluation: CIR1528/FR261, 8/2008. EDIS 2008 (6). https://doi.org/10.32473/edis-fr261-2008.
Costa, S., Caldeira, R., 2018. Bibliometric analysis of ocean literacy: an underrated term in the scientific literature. Mar. Policy 87, 149–157. https://doi.org/10.1016/j.marpol.2017.10.022.
Cummins, S., Snively, G., 2000. The effect of instruction on children's knowledge of marine ecology, attitudes toward the ocean, and stances toward marine resource issues. Can. J. Environ. Educ. 5, 305–324.
Dimopoulos, D., Paraskevopoulos, S., Pantis, J.D., 2008. The cognitive and attitudinal effects of a conservation educational module on elementary school students. J. Environ. Educ. 39 (3), 47–61. https://doi.org/10.3200/JOEE.39.3.47-61.
Ero-Tolliver, I., Lucas, D., Schauble, L., 2013. Young children's thinking about decomposition: early modeling entrees to complex ideas in science. Res. Sci. Educ. 43 (5), 2137–2152. https://doi.org/10.1007/s11165-012-9348-4.
Fauville, G., Strang, C., Cannady, M.A., Chen, Y.F., 2019. Development of the international ocean literacy survey: measuring knowledge across the world. Environ. Educ. Res. https://doi.org/10.1080/13504622.2018.1440381.
Fleming, L.E., Bruce Maycock, B., White, M.P., Depledge, M.H., 2019. Fostering human health through ocean sustainability in the 21st century. People Nat. 1, 276–283. https://doi.org/10.1002/pan3.10038.
Fortner, R.W., 1985. Relative effectiveness of classroom and documentary film presentations on marine mammals. J. Res. Sci. Teach. 21 (2), 115–126.
Fortner, R.W., Manzo, L., 2011. Great Lakes literacy principles. EOS Trans. Am. Geophys. Union 92 (13), 109. https://doi.org/10.1029/2011EO130002.
Fortner, R.W., Teates, T.G., 1980. Baseline studies for marine education: experiences related to marine knowledge and attitudes. J. Environ. Educ. 11, 11–19. https://doi.org/10.1080/00958964.1980.9941385.
Gambro, J.S., Switzky, H., 1994. A national survey of environmental knowledge in high school students: levels of knowledge and related variables. In: ERIC Document Reproduction Service No. Ed 379164.
Guest, H., Lotze, H.K., Wallace, D., 2015. Youth and the sea: ocean literacy in Nova Scotia, Canada. Mar. Policy 58, 98–107.
Hartley, B.L., Thompson, R.C., Pahl, S., 2015. Marine litter education boosts children's understanding and self-reported actions. Mar. Pollut. Bull. 90 (1), 209–217.
Hartley, B., Pahl, S., Holland, M., Alampei, I., Veiga, J.M., Thompson, R.C., 2018. Turning the tide on trash: empowering European educators and school students to tackle marine litter. Mar. Policy 96, 227–234.
Heck, N., Paytan, A., Potts, D.C., Haddad, B., 2016. Coastal residents' literacy about seawater desalination and its impacts on marine ecosystems in California. Mar. Policy 68, 178–186.
Heck, N., Lykkebo Petersen, K., Potts, D.C., Haddad, B., Paytan, A., 2018. Predictors of coastal stakeholders' knowledge about seawater desalination impacts on marine ecosystems. Sci. Tot. Environ. 639, 785–792. https://doi.org/10.1016/j.scitotenv.2018.05.163.
IPCC (Intergovernmental Panel on Climate Change), 2019. Special Report on the Ocean and Cryosphere in a Changing Climate. Geneva, Switzerland: IPCC. Available at: https://www.ipcc.ch/srocc/. (Accessed 10 August 2020).
Jerrim, J., Oliver, M., Sims, S., 2019. The relationship between inquiry-based teaching and students' achievement. New evidence from a longitudinal PISA study in England. Learn. Instr. 61, 35–44.
Kennish, M.J., 2000. Estuary Restoration and Maintenance. The National Estuary Program, CRC Press, Boca Raton, p. 372.
Kevrekidis, T., 2004. Seasonal variation of the macrozoobenthic community structure at low salinities in a Mediterranean Laggon, northern Aegean. Int. Rev. Hydrobiol. 89 (4), 407–425.
Kevrekidis, K., Kevrekidis, T., Mogias, A., Boubonari, T., Kantaridou, F., Kaisairi, N., Malea, P., Dounas, C., Thessalou-Legaki, M., 2023. Fisheries biology and basic life-cycle characteristics of the invasive blue crab *Callinectes sapidus* Rathbun in the estuarine area of the Evros River (Northeast Aegean Sea, eastern Mediterranean). J. Mar. Sci. Eng. 11, 462. https://doi.org/10.3390/jmse11030462.
Kim, J.-M., Anderson, D., Scott, S., 2013. Korean elementary school students' perceptions of relationship with marine organisms. Asia-Pac.Forum Sci. Learn. Teach. 14 (2), 10.
Klineberg, S.L., McKeever, M., Rothenbach, B., 1998. Demographic predictors of environmental concern: it does make a difference how it's measured. Soc. Sci. Q. 79 (4), 734–753.
Koulouri, P., Mogias, A., Mokos, M., Cheimonopoulou, M., Realdon, G., Boubonari, T., Previati, M., Tojeiro Formoso, A., Kideys, A.E., Hassaan, M.A., Patti, P., Korfiatis, K., Fabri, S., Juan, X., 2022. Ocean literacy across the Mediterranean Sea basin: evaluating middle school students' knowledge, attitudes, and behaviour towards ocean sciences issues. Mediterr. Mar. Sci. 23 (2), 289–301. https://doi.org/10.12681/mms.26797.
Lambert, J., 2005. Students' conceptual understandings of science after participating in a high school marine science course. J. Geosci. Educ. 53 (5), 531–539.
Lambert, J., 2006. High school marine science and scientific literacy: the promise of an integrated science course. Int. J. Sci. Educ. 28, 633–654. https://doi.org/10.1080/09500690500339795.
Liefländer, A.K., Bogner, F.X., 2014. The effects of children's age and sex on acquiring pro-environmental attitudes through environmental education. J. Environ. 45 (2), 105–117. https://www.researchgate.net/publication/260144107.
Liefländer, A.K., Fröhlich, G., Bogner, F.X., Schulz, W., 2013. Promoting connectedness with nature through environmental education. Environ. Educ. Res. , 370-384 19, 370–384. https://www.researchgate.net/publication/241231906.
Lin, Y.L., Wu, L.Y., Tsai, L.T., Chang, C.C., 2020. The beginning of marine sustainability: preliminary results of measuring students' Marine knowledge and ocean literacy. Sustainability 12, 7115.
Makki, M.H., Abd-El-Khalick, F., BouJaoude, S., 2003. Lebanese secondary school students' environmental knowledge and attitudes. Environ. Educ. Res. 9 (1), 21–33. https://doi.org/10.1080/13504620303468.
Markos, A., Boubonari, T., Mogias, A., Kevrekidis, T., 2017. Measuring ocean literacy in pre-service teachers: psychometric properties of the Greek version of the survey of ocean literacy and experience (SOLE). Environ. Educ. Res. 23 (2), 231–251.
McCrossan, C., Molloy, O., 2019. Measuring Individuals' Knowledge, Attitude andBehaviour on Specific Ocean Related Topics. In Proceedings of the 11th InternationalJoint Conference on Knowledge Discovery, Knowledge Engineering and KnowledgeManagement (IC3K 2019), pp. 325–332. ISBN: 978-989-758-382-7.
Mogias, A., Boubonari, T., Markos, A., Kevrekidis, T., 2015. Greek pre-service teachers' knowledge of ocean sciences issues and attitudes toward ocean stewardship. J. Environ. Educ. 46 (4), 251–270.
Mogias, A., Boubonari, T., Realdon, G., Previati, M., Mokos, M., Koulouri, P., Cheimonopoulou, M., 2019. Evaluating ocean literacy of elementary school students: preliminary results of a cross-cultural study in the Mediterranean region. Front. Mar. Sci. 6, 396. https://doi.org/10.3389/fmars.2019.00396.
Mogias, A., Boubonari, T., Kevrekidis, T., 2021. Examining the Presence of Ocean Literacy Principles in Greek Primary School Textbooks. Available online: Inter. Res. Geogr. Environ. Educ. https://doi.org/10.1080/10382046.2021.1877953.
Mogias, A., Boubonari, T., Kevrekidis, T., 2022. Tracing the occurrence of ocean sciences issues in Greek secondary education textbooks. Mediterr. Mar. Sci. 23 (2), 310–320. https://doi.org/10.12681/mms.27059.
Mokos, M., Cheimonopoulou, M.Th., Koulouri, P., Previa, M., Realdon, G., Santoro, F., Mogias, A., Boubonari, T., Gazo, M., Satta, A., Ioakeimidis, C., Tojeiro, A., Chicote, C. A., Papathanassiou, M., Kevrekidis, T., 2020a. Mediterranean sea literacy: when ocean literacy becomes region-specific. Mediterr. Mar. Sci. 21, 592–598. https://doi.org/10.12681/mms.23400.
Mokos, M., Giulia Realdon, G., Čižmek, I.Z., 2020b. How to increase ocean literacy for Future Ocean. Sustainability? The Influence of Non-Formal Marine Science Education. Sustainability 12, 10647. https://doi.org/10.3390/su122410647.
NAAEE, 2021. Guidelines for excellence environmental education materials. North American Association for Environmental Education (naaee) 98.
National Research Council (NRC), 1996. National Science Education Standards. The National Academies Press, Washington, DC.
Newton, A., Icely, J., Cristina,S., Brito, A., Cardoso, A.C., Colijn, F., Riva, S.D., Gertz, F., Hansen, J.W., Holmer, M., Ivanova, K., Leppäkoski, E., Canu , D.M., Chiara, M., Stephen, M., Murray, N., Morten, P., Razinkovas, A., Reizopoulou, S., Pérez-Ruzafa, A., Schernewski, G., Schubert, H., Carr, L., CosimoSolidoro, C. Viaroli, P., Zaldívar, J.-M., 2014. An overview of ecological status, vulnerability and future perspectives of European large shallow, semi-enclosed coastal systems, lagoons and transitional waters. Estuar. Coast. Shelf Sci. 140, 95e122. doi:https://doi.org/10.1016/j.ecss.2013.05.023.
Nicolaidou, A., Reizopoulou, S., Koutsoubas, D., Orfanidis, S., Kevrekidis, T., 2005. Biological components of Greek lagoonal ecosystems: an overview. Medit. Mar. Sci. 6 (2), 31–50.
NMEA (National Marine Educators Association), 2010. Ocean literacy scope and sequence for grades K-12, published in the national marine educator's association, U.S.A. Special Report 3 on The Ocean Literacy Campaign Featuring the Ocean Literacy Scope & Sequence for Grades K-12. Available at: http://www.oceanliteracy.net. (Accessed 26 March 2021).
NOAA (National Oceanic and Atmospheric Administration), 2013. Ocean literacy: The essential principles and fundamental concepts of Ocean Sciences for learners of all ages. Version 2. Available at: http://oceanliteracy.wp2.coexploration.org/?page_id=164. (Accessed 26 March 2021).
NOAA (National Oceanic and Atmospheric Administration), 2019. Principles and concepts for estuaries 101. NOAA Office for Coastal Management. Available at: https://coast.noaa.gov/data/estuaries/pdf/estuary-principles-and-concepts.pdf. (Accessed 26 March 2021).

Paredes-Coral, E., Mokos, M., Deprez, T., 2021. Mapping global research on ocean literacy. Implications for science, policy, and the blue economy. Front. Mar. Sci. 8, 648492 https://doi.org/10.3389/fmars.2021.648492.

Pérez-Ruzafa, A., Pérez-Ruzafa, I.M., Newton, A., Marcos, C., 2019. Coastal Lagoons: Environmental Variability, Ecosystem Complexity, and Goods and Services Uniformity. In: Wolanski, E., Day, J.W., Elliot, M., Ramachandran, R. (Eds.), Coasts and Estuaries. The Future. Chapter 15. Elsevier, pp. 253–276. https://doi.org/10.1016/B978-0-12-814003-1.00015-0.

Pérez-Ruzafa, A., María Pérez-Marcos, M., Marcos, C., 2020. Coastal lagoons in focus: their environmental and socioeconomic importance. J. Nat. Conserv. 57, 125886 https://doi.org/10.1016/j.jnc.2020.125886.

Plankis, B.J., Marrero, M.E., 2010. Recent ocean literacy research in United States public schools: results and implications. Int. Electron. J. Environ. Educ. 1 (1), 1–50.

Realdon, G., Mogias, A., Fabris, S., Candussio, G., Invernizzi, C., Paris, E., 2019. Assessing ocean literacy in a sample of Italian primary and middle school students. Rend. Soc. Geol. Ital. 49, 107–112.

Rehman, N., Zhan, W., Khalid, M.S., Iqbal, M., Mahmood, A., 2021. Assessing the knowledge and attitude of elementary school students towards environmental issues in Rawalpindi. Present Env. Sust. Dev. 15 (1), 5–21. https://doi.org/10.15551/pesd2021151001.

Rosseel, Y., 2012. Lavaan: an R package for structural equation modeling. J. Stat. Softw. 48, 1–36.

Schoedinger, S., Tran, L.U., Whitley, L., 2010. From the principles to the scope and sequence: a brief history of the ocean literacy campaign. NMEA Special Report 3, 3–7.

Schubel, J.R., Schubel, K.A., 2008. From ocean issues to solutions: the role of public ocean literacy. OCEANS, 1109/OCEANS. 2008.5151878.

Sigit, D.V., Miarsyah, M., Komala, R., Suryanda, R., Ichsan, I.Z., Fadrikal, R., 2020. EECN: analysis, potency, benefit for students knowledge and attitude to conserve mangroves and coral reefs. Inter. J. Instr. 13 (1), 125–138. https://doi.org/10.29333/iji.2020.1318a.

Stasinakis, P.K., 2021. Analysis of Greek textbooks about marine biology. Interdiscip. J. Environ. Sci. Educ. 17 (2), e2234.

Steel, B.S., Smith, C., Opsommer, L., Curiel, S., Warner-Steel, R., 2005. Public ocean literacy in the United States. Ocean Coast. Manag. 48, 97–114.

Stepath, C.M., 2007. Marine education: learning evaluations. J. Mar. Educ. 23 (2), 45–51.

Thompson, J., Curran, M.C., Cox, T., Thompson, J., Curran, M.C., Cox, T., 2016. "Capture" me if you can: estimating abundance of dolphin populations. Sci. Act. 53, 49–67. https://doi.org/10.1080/00368121.2015.1135863.

Tsai, L.T., Chang, C.C., 2019. Measuring ocean literacy of high school students: psychometric properties of a Chinese version of the ocean literacy scale. Environ. Educ. Res. 25 (2), 264–279. https://doi.org/10.1080/13504622.2018.1542487.

Tsai, L.T., Lin, Y.L., Chang, C.C., 2019. An assessment of factors related to ocean literacy based on gender-invariance measurement. Inter. J. Environ. Res. Public Health 16 (19), 3672. https://doi.org/10.3390/ijerph16193672.

UNESCO-IOC, 2021. The United Nations Decade of Ocean Science for Sustainable Development (2021–2030) Implementation plan – Summary. Paris, UNESCO (IOC Ocean Decade Series, p. 19.). Available at: https://www.oceandecade.org/decade-publications/.

Wells, N.W., Lekies, K.S., 2006. Nature and the life course: pathways from childhood nature experiences to adult environmentalism. Child. Youth Environ. 16 (1), 1–24. http://www.colorado.edu/journals/cye/.

Whitmee, S., Haines, A., Beyrer,C., Boltz, F., Capon, A.G., de Souza Dias, B.F., Ezeh, A., Frumkin, H., Gong, P., Head, P., Horton, R., Mace. G.M., Marten, R.; Myers, S.S., Nishtar, S., Osofsky, S.A.;Pattanayak, S.K., Pongsiri, M.J., Romanelli, C., Soucat, A., Vega, J., Yach, D., 2015. Safeguarding human health in the Anthropocene epoch: Report of The Rockefeller Foundation–Lancet Commission on planetary health. Lancet, 386 (10007), 1973–2028. doi:https://doi.org/10.1016/S0140-6736(15)60901-1.

Zerinou, I., Karasmanaki, E., Ioannou, K., Andrea, V., Tsantopoulos, G., 2020. Energy saving: views and attitudes among primary school students and their parents. Sustainability 12 (15), 6206. https://doi.org/10.3390/su12156206.

Zumbo, B.D., Gadermann, A.M., Zeisser, C., 2007. Ordinal versions of coefficients alpha and theta for Likert rating scales. J. Mod. Appl. Stat. Methods 6 (1), 21–29.