Australian Journal of Environmental Education (2023), **39**, 507–521
doi:10.1017/aee.2023.12

CAMBRIDGE UNIVERSITY PRESS

ARTICLE

Ocean literacy in Brazilian formal education: A tool for participative coastal management

Carmen Edith Pazoto, Michelle Rezende Duarte and Edson Pereira Silva

Laboratório de Genética Marinha e Evolução, Departamento de Biologia Marinha, Universidade Federal Fluminense (UFF), Niterói, Rio de Janeiro, Brazil
Corresponding author: Michelle Rezende Duarte; Email: michellerezendeduarte@yahoo.com.br

(Received 17 June 2022; revised 21 May 2023; accepted 21 May 2023; first published online 27 June 2023)

Abstract
Ocean literacy (OL) proposes to include ocean and marine environment-related content in school curricula. Such a topic has been deemed effective for citizens to develop actions and attitudes towards the health of marine ecosystems. This study aimed to verify the presence and frequency of OL principles and concepts in the Brazilian high school curriculum at the federal (National Curricular Parameters-PCN) and regional (Rio de Janeiro - Curricular Reference-RC) levels. Both PCN and RC contained OL-related content. Moreover, Biology and Geography were the subjects with the highest numbers of OL concepts, both in the PCN (26 and 27, respectively) and in the RC-RJ documents (28 and 24, respectively), while OL concepts were very little represented in History subject. A Mann–Whitney U-test did not indicate statistically significant differences in the number of concepts between PCN and RC-RJ ($p = 0.54$). A principal component analysis discriminated the documents according to subjects, regardless of their origin (federal or regional). These results provide an unbiased assessment of the relationship between the curriculum and OL in a strongly affected area (Rio de Janeiro State coastal zone [CZ]). Therefore, these results provide valuable support for managers seeking to promote effective CZ management practices and public compliance.

Keywords: teaching; marine education; curriculum; governance; content analysis; Rio de Janeiro

Introduction

A coastal zone (CZ), a region of interaction between the terrestrial and marine environment, encompasses some of the most valuable ecosystems on Earth, both in terms of biodiversity, productivity and ecosystem services for human development and well-being (UNEP, 2006). The Brazilian CZ is one of the largest worldwide and has an extension of 7500 km, of which 636 km are part of Rio de Janeiro State. Although it covers only 8.5% of the Brazilian CZ, it is a region with great ecological relevance and a variety of ecosystems (sandbanks, sandy beaches, mangroves and rocky shores), home to several species. In addition to being a densely inhabited area with 80% of the state's population (IBGE, 2011), it is also a hub of economic activity, including tourism, industry, ports, and oil and gas exploration (MMA, 2008). Despite its ecological and economic relevance, Rio de Janeiro CZ has been accumulating signs of environmental decay due to problems such as urban settlement sprawling with no infrastructure, lack of sanitation, improper garbage disposal, floods, in addition to oil spill accidents (Aguiar, 2017; Pinheiro & Silva, 2021).

As a way of combating the impacts on the CZ in Rio de Janeiro, studies have pointed out the relevance of a governance system that considers the interdependence between human and

© The Author(s), 2023. Published by Cambridge University Press on behalf of Australian Association for Environmental Education. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

environmental factors in problem management (Crowder et al., 2006; Young et al., 2007). Governance is the process by which different elements of society exert power and authority, influencing and enacting policies and decisions regarding public life, as well as economic and social development (Ehler, 2003). Governance is distinct from government and involves other mechanisms, institutions, the private sector and civil society. The goal is to solve common problems and achieve strategic objectives through collaborative decision-making (Jones, 2012; Juda, 1999). Governance processes can take many forms, depending on their goals and motivations, among which are top-down and bottom-up models. The first model assumes a top-down approach, where the information flow is directed downwards, and there is a separation between the elaboration and implementation of public policies. This model is characterised by centralised actions by the state. In contrast, the bottom-up model assumes that different stakeholders play an active and decisive role in defining common agendas and implementing policies of mutual interest.

Regarding coastal and marine environments, conservation and management measures have transitioned from top-down governance models, directed by governments, towards more participatory models, thus following a bottom-up orientation with community involvement in decision-making (McKinley & Fletcher, 2010). In Brazil, the *Plano Nacional de Gerenciamento Costeiro*-PNGC (National Coastal Management Plan), established in 1988, provides the framework for coastal management policies, plans and programmes of federative units and municipalities, in addition to regulating the environmental licensing of activities that can impact coastal ecosystems. The PNGC establishes the legal basis for an integrated, decentralised and participatory management of coastal ecosystems and their resources (Wever, Glaser, Gorris & Ferrol-Schulte, 2012). However, the participation of society in the decision-making, planning and management of the CZs is still limited. One of the reasons is the difficulty of ordinary people to understand technical terms in reports and meetings wherein management plans are discussed (Marroni & Asmus, 2013). Thus, initiatives to empower citizens to take an active and conscious role in addressing environmental problems in CZs are essential (Wever et al., 2012).

Ocean literacy (OL) refers to 'the understanding of the ocean's influence on humans and their influence on the ocean'. It emerged in the United States in the early 2000s, from a movement organised by scientists, educators, curriculum developers and other stakeholders interested in including ocean-related topics in school curricula (Ocean Literacy Network, 2020). A collaborative effort of the initial founders of OL defined what knowledge about the ocean all North American students should know after finishing school. It was summarised into seven essential principles and 45 fundamental concepts (Table 1), which were published in the document 'Ocean Literacy - The Essential Principles of Ocean Science K-12' (Schoedinger, Tran, & Whitley, 2010). Furthermore, it was established what is expected of an ocean literate person: (1) to understand fundamental concepts about the functioning of the ocean, (2) to speak in a meaningful way about marine environment-related subjects and (3) to make informed and responsible decisions for the ocean and its resources (Ocean Literacy Network, 2020).

In its almost 20 years of existence, OL has been identified as an important alternative to make individuals and society take actions and attitudes towards the health of seas and the ocean (Guest, Lotze, & Wallace, 2015). However, studies have indicated that the populations of several countries still have limited knowledge about the ocean. Steel et al. (2005), for example, observed that the adult population of the United States has little information on oceanic and coastal issues. In Europe, Gelcich et al. (2014) reported that general populations in 10 European countries felt only moderately informed about impacts on marine environments. Guest et al. (2015) investigated the knowledge of elementary school students in Canada, and Chen and Tsai (2016) studied higher education students in Taiwan. These authors concluded that students value marine environments but have low to moderate knowledge of marine environments. In Brazil, the situation is no different, in a national survey carried out in 2011 (CEMBRA, 2019) it was pointed out that, for Brazilians, the importance of the sea is limited to a source of food (67%) and leisure (39%).

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

Table 1. Essential principles and fundamental concepts of Ocean Literacy (Ocean Literacy Network, 2020) and their presence and frequency in the documents *Parâmetros Curriculares Nacionais* (PCN; National Curricular Parameters in English) and *Referencial Curricular do Rio de Janeiro* (RC; Rio de Janeiro Curricular Reference in English) for the subjects Biology (PCN-B and RC-B), Geography (PCN-G and RC-G) and History (PCN-H and RC-H)

Principle	Concept*	PCN-B	PCN-G	PCN-H	RC-B	RC-G	RC-H
1: The Earth has one big ocean with many features.	A: The ocean is the defining physical feature on our planet Earth—covering approximately 70% of the planet's surface.		1	1		3	
	B: Ocean basins are composed of the seafloor and all of its geological features and vary in size, shape and features due to the movement of Earth's crust (lithosphere).		1			1	
	C: Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of Earth's rotation (Coriolis effect), the Sun and water density differences.		1			1	
	D: Sea-level changes as plate tectonics cause the volume of ocean basins and the height of the land to change. It changes as ice caps on land melt or grow. It also changes as sea water expands and contracts when ocean water warms and cools.		1				
	E: Most of Earth's water (97%) is in the ocean. Seawater has unique properties.		1				
	F: The ocean is an integral part of the water cycle and is connected to all of Earth's water reservoirs via evaporation and precipitation processes.	1	1		1	1	
	G: All major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to coastal estuaries and to the ocean.	6	4		1	5	
	H: Although the ocean is large, it is finite and resources are limited.	2	3	1	1	1	

(*Continued*)

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

Table 1. (*Continued*)

Principle	Concept*	PCN-B	PCN-G	PCN-H	RC-B	RC-G	RC-H
2: The ocean and life in the ocean shape the features of the Earth.	A: Many earth materials and biogeochemical cycles originate in the ocean.	1	1		1		
	B: Sea-level changes over time and shaped the surface of land.		1			1	
	C: Erosion occurs in coastal areas as wind, waves, and currents in rivers and the ocean, and the processes associated with plate tectonics move sediments.		1			2	
	D: The ocean is the largest reservoir of rapidly cycling carbon on Earth.		1			1	
	E: Tectonic activity, sea-level changes and force of waves influence the physical structure and landforms of the coast.		1			2	
3: The ocean is a major influence on weather and climate.	A: The interaction of oceanic and atmospheric processes controls weather and climate by dominating the Earth's energy, water and carbon systems.	1	2		1	3	
	B: The ocean moderates global weather and climate.					1	
	C: Heat exchange between the ocean and atmosphere can result in dramatic global and regional weather phenomena, impacting patterns of rain and drought.					1	
	D: Most rain that falls on land originally evaporated from the tropical ocean.				1		
	E: The ocean dominates the Earth's carbon cycle.	2	2		3	3	
	F: The ocean has had and will continue to have, a significant influence on climate change.		2		1	3	
	G: Changes in the ocean-atmosphere system can result in changes to the climate.		1		1	3	

(*Continued*)

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

Table 1. (*Continued*)

Principle	Concept*	PCN-B	PCN-G	PCN-H	RC-B	RC-G	RC-H
4: The ocean makes Earth habitable.	A: Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.	1			3		
	B: The ocean is the cradle of life; the earliest evidence of life is found in the ocean.	4			3		
	C: The ocean provided and continues to provide water, oxygen, and nutrients, and moderates the climate needed for life to exist on Earth.	5	2		3	5	
5: The ocean supports a great diversity of life and ecosystems.	A: Ocean life ranges in size from the smallest living things, microbes, to the largest animal on Earth, blue whales.	4			1		
	B: Most of the organisms and biomass in the ocean are microbes. Microbes are the most important primary producers in the ocean.	10			3		
	C: Most of the major groups that exist on Earth are found exclusively in the ocean and the diversity of major groups of organisms is much greater in the ocean than on land.	8			2		
	D: Ocean biology provides many unique examples of life cycles, adaptations, and important relationships among organisms that do not occur on land.	7			3		
	E: The ocean provides a vast living space with diverse and unique ecosystems from the surface through the water column and down to, and below, the seafloor.	3			1		
	F: Ocean ecosystems are defined by environmental factors and the community of organisms living there.	6			1		
	G: There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms.	7			5		
	H: Zonation patterns influence organisms' distribution and diversity.	4			1		
	I: Estuaries provide important and productive nursery areas for many marine and aquatic species.	7			1		

(*Continued*)

Table 1. (*Continued*)

Principle	Concept*	PCN-B	PCN-G	PCN-H	RC-B	RC-G	RC-H	
6: The ocean and humans are inextricably interconnected.	A: The ocean affects every human life.	1			1	1		
	B: The ocean provides foods, medicines, and mineral and energy resources. It supports jobs, and national economies, serves as a highway for transportation of goods and people, and plays a role in national security.	1	11	3	2	8	6	
	C: The ocean is a source of inspiration, recreation, rejuvenation and discovery. It is also an important element in the heritage of many cultures.	2	2	1		1		
	D: Humans affect the ocean in a variety of ways.	1	4		1	10		
	E: Changes in ocean temperature and pH due to human activities can affect the survival of some organisms and impact biological diversity.	12	4		4	6		
	F: Much of the world's population lives in coastal areas.							
	G: Everyone is responsible for caring for the ocean.	9	4	1	5	6		
7: The ocean is largely unexplored.	A: The ocean is the last and largest unexplored place on Earth.		1					
	B: Exploration, experimentation and discovery are required to better understand ocean systems and processes.		1					
	C: Over the last 50 years, use of ocean resources has increased significantly.	2	2	1	3	2		
	D: New technologies, sensors and tools are expanding our ability to explore the ocean.		1		2			
	E: Use of mathematical models is an essential part of understanding the ocean system.	1						
	F: Ocean exploration is truly interdisciplinary.							
		N1	26	27	6	28	24	1
		N2	108	57	8	56	71	6

N1- refers to the number of concepts covered in the 45 OL basic concepts for each document and subject; N2- refers to the total number of occurrences of the 45 OL basic concepts for each document and subject.*The complete description of OL concepts can be found at: https://oceanliteracy.unesco.org/wp-content/uploads/2020/09/OceanLiteracyGuide_V3_2020-8x11-1.pdf.

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

Regarding secondary education, the literature is restricted to three papers. Low et al. (2013) investigated misconceptions about marine sciences presented by Taiwanese students and identified that they had moderate knowledge, with an average rate of correct answers about marine concepts of 50%. Cheimonopoulou et al. (2022) assessed the knowledge about marine issues of students from the Mediterranean region of Italy and Greece and identified a rate of 40% correct answers for questions related to marine concepts. Unlike the first two studies, Chang, Tsai, and Meliana (2023) assessed the OL level of students at an Indonesian maritime vocational school that presents a curriculum focused on the marine environment and obtained 70% correct answers on marine issues and concluded that, in this case, students have a basic level OL.

To mitigate students' insufficient understanding of the ocean and promote OL, some initiatives have been proposed. The Blue School Program in Portugal proposes that participating schools develop a marine-focused curriculum to enhance students' oceanic literacy (Costa et al., 2021). In South Africa, the Two Oceans Aquarium created initiatives to promote OL that encompass creating a marine science curriculum, aiding schools and teachers in implementing this curriculum and providing marine-based holiday programmes for high school students (Stevens, 2021). In other cases, activities may be more specific, such as developing ocean-themed games (Koenigstein, Hentschel, Heel & Drinkorn, 2020), constructing physical models to aid understanding of oceanic concepts (Curran, Bower, & Furey, 2017) and creating iBooks that complement formal teaching curricula with OL content (McHugh, McCauley, Davison, Raine & Grehan, 2020). In 2021, the city of Santos in Brazil enacted a law that requires the inclusion of OL in the curriculum of schools located in the municipality (Santos Municipal Law No. 3935, 2021).

OL has been recognised in studies (Dupont & Fauville, 2017; Ryabinin et al., 2019; Visbeck, 2018) and intergovernmental reports (United Nations, 2018) as a bottom-up initiative that mobilises and engages society on ocean-related issues. Since public knowledge is essential for bottom-up coastal management and formal education has a wide reach, including OL in school curricula is a strategic tool for equipping the population with the necessary technical skills to make informed decisions. Therefore, managers interested in economic environmental management and societal mobilisation should consider implementing OL initiatives (Visbeck, 2018). As observed by Lucrezi et al. (2019), educational activities related to OL principles and concepts in school curricula have successfully engaged Mozambique's population in marine environmental conservation and management processes.

Encouraging the implementation of OL in school curricula can promote social engagement in the rational and sustainable management of the CZ in Rio de Janeiro State, both in the present and future. This study aims to investigate the presence of content related to the seven essential principles and 45 fundamental concepts of OL in the formal education curriculum in Brazil, with a focus on Rio de Janeiro. Therefore, the findings of this study will provide useful information for engaging society in bottom-up management practices for CZ.

Material and Methods

Analysed documents

The following documents were analysed and compared: (1) 'Ocean Literacy – The Essential Principles and Fundamental Concepts of Ocean Sciences for Learners of All Ages' (OL-PC); (2) *Parâmetros Curriculares Nacionais* (PCN; National Curriculum Parameters in English); and (3) *Referencial Curricular do Rio de Janeiro* (RC-RJ; Curricular Reference of the State of Rio de Janeiro in English).

The OL-PC, which is in its third version, provides an overview of OL, including its definition, goals and history, as well as its seven essential principles and 45 fundamental concepts (Ocean Literacy Network, 2020). This guide describes the ocean knowledge that everyone should have, which is systematised in these seven principles and 45 concepts (Ocean Literacy Network, 2020).

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

The PCN is a federal document that outlines school curriculum contents for Brazilian schools. It was published in 2000 to guide regional curricula for each subject and ensure a minimum common content for all Brazilian students. Moreover, each Brazilian federative unit develops its curricular framework, which includes a minimum common content as well as regional and local characteristics that reflect the unique aspects of its society, culture and economy (Brasil, 2000). As a result, the PCN and various RCs may exhibit some specificities. The RC-RJ was published in 2012.

In this study, we analysed PCN and RC-RJ for high school, which is the final stage of Brazilian basic education, lasting three years and covering young people from 15 to 17 years of age. The curricular contents investigated were restricted to Biology, Geography and History, since previous research (Pazoto et al., 2021) had already shown that these subjects contain 88.7% of the words related to the ocean and marine environment in both PCN and RC-RJ.

Data analysis

We analysed the inclusion of OL principles and concepts in school curricula using the content analysis method by Bardin (2011), which involves identifying, extracting and organising relevant information from written sources. To accomplish this, we used OL principles and concepts as search categories to guide our analysis of the documents. First, we read the entire set of documents to gain a general understanding of their content. Next, we identified sections of each document that pertained to one or more OL principles or concepts and coded them accordingly. As an example, excerpts that dealt with 'source of pollution', 'polluted areas', 'hydrographic networks', etc. were identified as related to concept G from principle 1, which states that 'The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean; therefore, rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to coastal estuaries and the ocean'. Similarly, as an example, excerpts related to concept A from principle 2 were identified. This principle states that 'Many earth materials and biogeochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks'. The identified excerpts included terms such as 'chemical elements', as well as specific words like 'oxygen', 'carbon' and 'nitrogen'. Through this process, the presence of OL principles and concepts was identified in the corpus of documents. Finally, the presence (if identified) and frequency (number of times) of each OL principle and concept were found within the subject areas of Biology, Geography and History in both the PCN and RC-RJ documents. Only excerpts that explicitly related to OL principles and concepts were coded, and those passages that only tangentially touched on the subject were excluded to avoid ambiguity in the results.

A principal component analysis (PCA) was conducted on the frequency of OL principles and concepts (totalling 45 variables) for each of the three subjects in the two documents. This technique linearly converts a set of correlated variables into another set of uncorrelated variables that can explain the information from the original set. The new variables, known as principal components (PCs), are graphically represented by the x and y axes (PC1 and PC2, respectively). The former provides the highest explanation of the original data variation, and the latter has the second-highest, and so on until the total variance in original data is accounted for. These axes (PCs) comprise a synthetic way of reducing several redundant variables into super-variables (PCs), which are easily visualised but not necessarily easily interpreted. This exploratory multivariate analysis is used to identify patterns and trends, allowing to analyse of multiple variables simultaneously, generating knowledge on the importance of the studied variables (Abdi & Williams, 2010; Hair et al., 2009).

Non-parametric Mann–Whitney U-test (between two datasets) and Kruskal–Wallis (between more than two datasets) tests were used to determine the statistical significance of variances in the frequency of OL principles and concepts among the investigated subjects in each document. The

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

Table 2. *p*-values from two-by-two comparison of Ocean Literacy concepts' occurrence frequency among Biology (Bio), Geography (Geo) and History (Hist) subjects in Brazilian curricular documents (PCN and RC-RJ) using the Mann–Whitney U-test

Document-Subject	PCN-Bio	PCN-Geo	PCN-Hist	RC-Bio	RC-Geo	RC-Hist
PCN-Bio	–	0.342	2.90×10^{-6}*	0.431	0.359	2.87×10^{-8}*
PCN-Geo	1.000	–	3.30×10^{-6}*	0.753	0.997	1.63×10^{-8}*
PCN-Hist	4.35×10^{-5}*	4.96×10^{-5}*	–	1.24×10^{-6}*	2.57×10^{-5}*	0.058
RC-Bio	1.000	1.000	1.86×10^{-5}*	–	0.815	7.13×10^{-9}*
RC-Geo	1.000	1.000	0.0004*	1.000	–	2.00×10^{-7}*
RC-Hist	4.31×10^{-7}*	2.45×10^{-7}*	0.872	1.07×10^{-7}*	3.00×10^{-6}*	–

The *p*-values obtained before the Bonferroni correction are above the diagonal, while those obtained after the correction are below it.
*Significant results.

significance level to reject the null hypothesis was 0.05. To avoid errors from multiple comparisons, the probabilities associated with non-parametric tests were corrected using the Bonferroni correction. Non-parametric tests were chosen due to the non-normal distribution of variance and heteroscedasticity, which were evaluated using the Shapiro–Wilk and Levene's tests, respectively. All analyses were performed using PAST software version 2.08 (Hammer, Harper, & Ryan, 2001).

Results

The Biology subject had all seven OL principles in both the PCN and RC-RJ. Geography, in turn, had six principles in both documents, while History had three principles in the PCN and one in the RC-RJ. Biology and Geography had the highest number of OL concepts, with 26 and 27 concepts in the PCN document and 28 and 24 concepts in the RC-RJ document, respectively. History had three concepts in the PCN and one in the RC-RJ document (Table 1).

The Kruskal–Wallis test showed significant differences between subjects in both documents ($p = 2.39 \times 10^{-9}$). The Mann–Whitney U-test indicated that History differed significantly from Biology and Geography in both documents, remaining significant after the Bonferroni correction (Table 2). However, the Mann–Whitney U-test did not find significant differences between the number of concepts present in the PCN and RC-RJ documents ($p = 0.54$).

The PCA revealed that PC1 recovered 64.26% of the total variation and distinguished two groups in both PCN and RC-RJ: one formed by Biology and the other with Geography and History. PC2 recovered 26.83% of the variation and discriminated Geography and History between the PCN and RC-RJ (Figure 1). Concepts 6E (covers the various impacts caused by humans on the ocean; 0.40), 5B (addresses the microscopic life diversity harboured in the ocean; 0.39) and 5C (addresses the macroscopic life diversity harboured in the ocean; 0.31) had the highest correlation index with PC1. Conversely, concepts 6D (describes the different ways humans may affect the ocean and marine environments; 0.57), 6B (discusses the variety of advantages humans get from coastal-marine environments; 0.38) and 1G (explores the link between the ocean and bodies of freshwater on land; 0.30) had the highest correlation index with PC2.

Discussion

The significance of incorporating OL principles and concepts into the school curriculum to enhance societal understanding and consciousness of marine environmental issues has been widely acknowledged (Guest et al., 2015; Payne & Zimmerman, 2010; Santoro, Santin, Scowcroft,

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

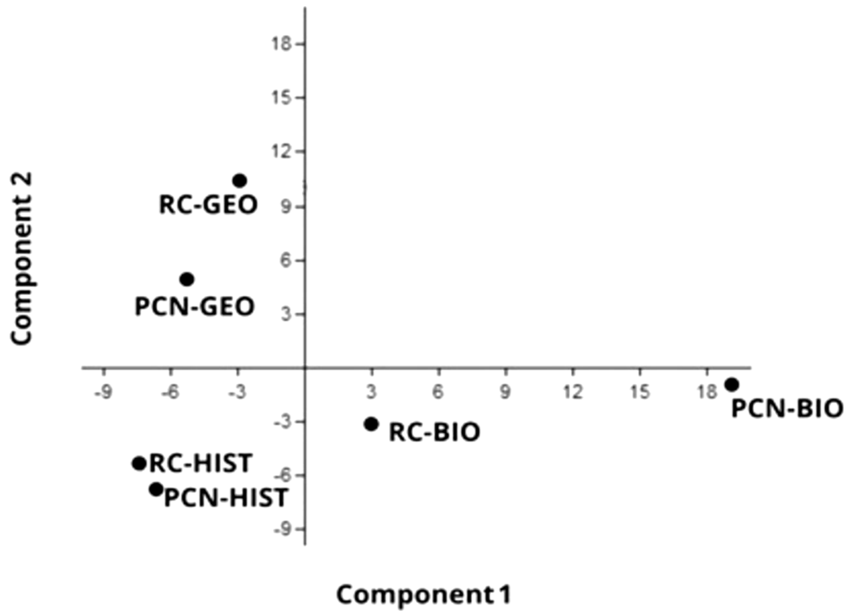

Figure 1. Principal component analysis (PCA) scatter plot for Biology (BIO), Geography (GEO) and History (HIST) subjects in the PCN (National Curriculum Parameters) and RC (Curricular Reference of the State of Rio de Janeiro) documents.

Fauville & Tuddenham, 2017; United Nations, 2018). Thus, the analysis of school curricula is the first initiative so that the potential and challenges of including these contents are achieved (Pazoto et al., 2021). Despite the acknowledged importance of OL, there has been a paucity of research examining its presence in formal education curricula. Two prior studies conducted in Brazil analysed national and regional curriculum documents at the elementary school level, with one study identifying only a small fraction of content related to ocean and marine themes (Pazoto et al., 2021), and the other concluding that only five of the seven OL principles and 14 concepts were represented in the analysed documents (Pazoto et al., 2022). In contrast, our study found that the Brazilian secondary education curriculum incorporates the vast majority of OL principles and concepts.

Besides the aforementioned studies, only three studies worldwide have focused on investigating the presence of OL-related content in formal education curricula. Hoffman and Barstow (2007) investigated Earth Science Education Standards from the 50 US states and found that only 20 out of 45 OL concepts were included. McPherson, Wright, and Tyedmers (2018a) analysed the curricula of high school science subjects in the province of Nova Scotia, Canada, and encountered that of the 11 curricula analysed, only three addressed OL, encompassing between two and 18 concepts. In turn, Chang, Hirenkumar, and Wu (2021) found that the National Educational Standards of India encompassed an average of 11.3 OL concepts. Otherwise, the Brazilian school curriculum approached a larger number of OL principles and concepts both at the federal and regional levels (Rio de Janeiro State). However, unlike Chang et al. (2021) who identified Geography as the subject including most of the OL concepts, in Brazil, both Geography and Biology contained more than 50% of the OL concepts, which were less represented in History.

To redress the lack of ocean-related content in school curricula in some countries (Chang et al., 2021; Hoffman & Barstow, 2007; McPherson, Wright, & Tyedmers, 2018a), activities have been suggested that complement the curriculum or promote OL beyond the curriculum. McHugh et al. (2020) proposed building an iBook with OL content for high school science classes and concluded that it contributed to increasing students' OL. Koenigstein et al. (2020) developed a game about ocean issues for high school students and found that it was positive in promoting OL topics related to marine sustainability. Fauville et al. (2019) is an edited collection that provides numerous case studies and examples of effective pedagogical approaches. Fauville (2017) provides a good example of how students can benefit from interacting with a marine scientist, albeit virtually and Tran et al. (2010) demonstrate how research findings can inform practice.

In the present study, PCA was used to investigate potential patterns and trends in both documents regarding OL principles and concepts. Our findings indicated that documents were separated not by their origin (federal or regional) but by school subjects. Differences between subjects were statistically significant and already expected, as each addresses specific knowledge and, therefore, has different goals and skills (Brasil, 2000). Thus, OL concepts with greater correlation with PC1 that separate Biology from Geography and History have contents traditionally addressed in Biology and are only found there. For example, concepts 5B and 5C address microscopic and macroscopic diversity of environmental marine life, respectively, in addition to 6E, which discusses the impacts of humans on the ocean. The latter concept, although addressed in the three subjects, was more often recorded in Biology. Likewise, the concepts that mostly contribute to distinguishing Geography from History by PC2 (1G: explores the link between the ocean and bodies of freshwater on land; 6B: marine environments benefits; and 6D: impacts of human beings on marine environments) are most included in Geography contents.

In each grade of high school, Brazilian students receive instruction in all subjects. Therefore, Biology and Geography complement each other in terms of OL principles and concepts. Together, these subjects incorporate 40 out of 45 OL concepts at the federal level (PCN) and 38 at the regional level (RC-RJ), a difference that is neither relevant nor statistically significant. Furthermore, the PCN and RC-RJ should not be seen as exclusive but rather complementary in defining classroom content. Together, they encompass all seven principles and 43 out of 45 OL concepts, except for 6F (CZs risks to natural phenomena such as tsunamis, hurricanes, cyclones, sea-level rise, waves and storms) and 7F (ocean exploration and study interdisciplinarity). In short, OL can be incorporated into the Brazilian curriculum, especially in Biology and Geography subjects. This is in line with a study by Gough (2017), which identified these subjects as the best for introducing OL knowledge into Australian school curricula. However, the OL theme has an interdisciplinary nature and can be included in almost all school subjects (Santoro et al., 2017). Therefore, future work should analyse the potential for OL inclusion in other school subjects.

Although the Brazilian curricula, as represented by the subjects analysed, encompass almost all OL content, inclusion in the curricula alone does not guarantee its effective implementation in the classroom. Other factors must also be considered, such as how the content is addressed by teachers, which in turn depends on their previous training (Payne et al., 2010). McPherson, Wright, and Tyedmers (2018b) and Mogias et al. (2015) found that teacher training courses in Greece and Canada, respectively, do not adequately prepare teachers for marine environments, with many of them feeling unprepared to teach the subject in class. Thus, more than simply being included in the curricula, teachers must be well trained in OL content to effectively incorporate it into their teaching.

Including OL in schools can help overcome one of the necessary but insufficient points for social participation in bottom-up governance strategies: the lack of knowledge (Marroni & Asmus, 2013; Wever et al., 2012). OL addresses several CZ-threatening problems in Rio de Janeiro State, such as the unplanned urban sprawl consequences (Aguiar, 2017), which are addressed in concepts 6F (CZ population density), 6D (ways humans affect the sea) and 1G (water body connectivity and transport of pollutants, debris, and others to the sea). Another issue in the CZ of Rio de Janeiro is the intensification of extreme events and sea-level rise due to climate change (Aguiar & Ervatti, 2020; Egler & Gusmão, 2014), which is addressed in principle 3 and its concepts. On the other hand, Rio de Janeiro benefits from several resources extracted from marine environments, such as oil and natural gas (Souto, Polette, & Kampel, 2009), which is highlighted in concept 1H. This concept emphasises the finite nature of marine resources, while concepts 6B

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

and 6C address various services and resources provided by marine environments. Additionally, some OL concepts are related to management itself, addressing the shortage of marine resources (1H), individual and collective responsibility in resource management (6G), and the need for sustainable use of these environments (7C).

The Brazilian curriculum at both federal and regional levels in Rio de Janeiro contains knowledge about marine environments. However, it has not been effectively integrated into schools. Furthermore, even when knowledge is present, it is not enough, as Enlightenment-era theses from the 16th to 18th centuries have argued. Mobilisation and engagement from society are necessary to address the challenges of participatory management. Therefore, it is through concrete societal objectives that school curriculum and teacher training can fulfil their role in spreading content related to the ocean and marine environments. Education systems often only reproduce dominant economic models, perpetuating a vicious cycle. To break this cycle and become agents of transformation, there is a social urgency for change.

Conclusion

Both federal (PCN) and regional (RC-RJ) documents cover almost all OL-related content in Biology and Geography subjects, indicating good coverage of marine environments in Brazilian high school curricula. PCA proved to be effective for multiple variables simultaneously, differentiated documents by subject, regardless of being of federal or regional origin. However, coverage alone does not guarantee knowledge will reach classrooms and empower citizens to make informed decisions. Teachers trained in OL themes must be associated with a society aware of their relationship with marine environments and their consequences. It would seem that there is a very long way to go, still, to promote engaged and responsible participatory coastal management.

Acknowledgements. This article was developed as part of the Project PDPA-UFF-PMN (TERMO DE CONVÊNIO N° 002/2021) 'Educação Patrimonial, Cultura Oceânica e Cidadania: Usando Bens Naturais e Culturais como Recursos Educacionais na Construção da "Niterói Que Queremos"' (DO 18-05-2021-TERMO DE CONVÊNIO N° 002-2021/ PT-UFF 61 - Projeto FEC 4447).

Competing interests. None.

Financial support. This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

Ethical standard. None.

References

Abdi, H., & Williams, L.J. (2010). Principal components analysis. *Wiley Interdisciplinary Reviews: Computational Statistics*, *2*(4), 433–459. DOI: 10.1002/wics.101.

Aguiar, T.C. (2017). Uma visão integrada dos impactos ambientais no estado do Rio de Janeiro. In G.J. Marafon & M.A. Ribeiro (Eds.), *Revisitando o território fluminense VI* (pp. 65–86). Rio de Janeiro, SciELO – EDUERJ.

Aguiar, T.M.C.B., & Ervatti, M. (2020). Coastal vulnerability in the face of climate change and public policies in the city of Rio de Janeiro: Are we prepared? *Novos Cadernos NAEA*, *23*, 161–178.

Bardin, L. (2011). *Análise de conteúdo*. *70*, São Paulo: Edições.

Brasil. (2000). PCNEM – Parâmetros Curriculares Nacionais Ensino Médio. Retrieved May 1, 2020 from http://portal.mec.gov.br/programa-saude-da-escola/195-secretarias-112877938/seb-educacao-basica-2007048997/12598-publicacoes-sp-265002211.

CEMBRA (2019). *O Brasil e o mar no século XXI: Relatório aos tomadores de decisão do país*. Centro de Excelência para o Mar Brasileiro, 2nd edition, Niterói: BHMN.

Chang, C.C., Hirenkumar, T.C., & Wu, C.K. (2021). The concept of ocean sustainability in formal education - comparative ocean literacy coverage analysis of the educational standards of India and the USA. *Sustainability*, *13*(8), 4314. DOI: 10.3390/su13084314.

Chang, C.C., Tsai, L.T., & Meliana, D. (2023). The concept of ocean sustainability in high school: Measuring the ocean literacy of vocational high school students in Indonesia. *Sustainability*, *15*(2), 1043. DOI: 10.3390/su15021043.

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

Cheimonopoulou, M., Koulouri, P., Previati, M., Realdon, G., Mokos, M., & Mogias, A. (2022). Implementation of a new research tool for evaluating Mediterranean Sea Literacy (MSL) of high school students: A pilot study. *Mediterranean Marine Science*, *23*(2), 302–309. DOI: 10.12681/mms.29712.

Chen, C.L., & Tsai, C.H. (2016). Marine environmental awareness among university students in Taiwan: A potential signal for sustainability of the oceans. *Environmental Education Research*, *22*(7), 958–977. DOI: 10.1080/13504622.2015.1054266.

Costa, R.L., Mata, B., Silva, F., Conceição, P., & Guimarães, L. (2021). Fostering ocean-literate generations: The Portuguese Blue School. In K.C. Koutsopoulos & J.H. Stel (Eds.), *Ocean literacy: Understanding the ocean* (pp. 241–273). Switzerland: Springer Nature.

Crowder, L.B., Osherenko, G., Young, O.R., Airamé, S., Norse, E.A., Baron, N., et al. (2006). Resolving mismatches in U.S. Ocean Governance. *Science*, *313*(5787), 617–618. DOI: 10.1126/science.1129706.

Curran, M.C., Bower, A.S., & Furey, H.H. (2017). Detangling spaghetti: Tracking deep ocean currents in the Gulf of Mexico. *Science Activities: Classroom Projects and Curriculum Ideas*, *54*(3-4), 59–69. DOI: 10.1080/00368121.2017.1322031.

Dupont, S., & Fauville, G. (2017). Ocean literacy as a key toward sustainable development and ocean governance. In P. Nunes, L.E. Svensson & A. Markandya (Eds.), *Handbook on the economics and management of sustainable oceans* (pp. 519–537). Cheltenham: Edward Elgar Publishers.

Egler, C.A.G., & Gusmão, P.P. (2014). Coastal management and climate change adaptation: The case of Rio de Janeiro Metropolitan Region, Brazil. *Journal of Integrated Coastal Zone Management*, *14*(1), 65–80. DOI: 10.5894/rgci370.

Ehler, C.N. (2003). Indicators to measure governance performance in integrated coastal management. *Ocean & Coastal Management*, *46*(3-4), 335–345. DOI: 10.1016/S0964-5691(03)00020-6.

Fauville, G. (2017). Questions as indicators of ocean literacy: Students' online asynchronous discussion with a marine scientist. *International Journal of Science Education*, *39*(16), 2151–2170. DOI: 10.1080/09500693.2017.1365184.

Fauville, G., Payne, D.L., Marrero, M.E., Lantz-Andersson, A., & Crouch, F. (2019). *Exemplary practices in marine science education. A resource for practitioners and researchers*, Switzerland: Springer Nature. DOI: 10.1007/978-3-319-90778-9.

Gelcich, S., Buckley, P., Pinnegar, J.K., Chilvers, J., Lorenzonic, I., Terryd, G., et al. (2014). Public awareness, concerns, and priorities about anthropogenic impacts on marine environments. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(42), 15042–15047. DOI: 10.1073/pnas.1417344111.

Gough, A. (2017). Educating for the marine environment: Challenges for schools and scientists. *Marine Pollution Bulletin*, *124*(2), 633–638. DOI: 10.1016/j.marpolbul.2017.06.069.

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

Hair, J.F.J., Black, W.C., Babin, B.J., Anderson, R.E., & Tathan, R.L. (2009). *Análise multivariada de dados*. Porto Alegre: Bookman.

Hammer, Ø., Harper, D.A.T., & Ryan, P.D. (2001). PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, *4*, 1–9.

Hoffman, M., & Barstow, D. (2007). *Revolutionizing Earth system science education for the 21st century: Report and recommendations from a 50-State analysis of Earth science education standards*. Washington: National Oceanic and Atmospheric Administration.

IBGE. (2011). Censo demográfico. Retrieved September 01, 2021 from https://censo2010.ibge.gov.br/.

Jones, P.J.S. (2012). Marine protected areas in the UK: Challenges in combining top-down and bottom-up approaches to governance. *Environment Conservation Journal*, *39*(3), 248–258. DOI: 10.1017/S0376892912000136.

Juda, L. (1999). Considerations in developing a functional approach to the governance of large marine ecosystems. *Ocean Development & International Law*, *30*(2), 89–125. DOI: 10.1080/009083299276203.

Koenigstein, S., Hentschel, L.H., Heel, L.C., & Drinkorn, C. (2020). A game-based education approach for sustainable ocean development. *ICES Journal of Marine Science*, *77*(5), 1629–1638. DOI: 10.1093/icesjms/fsaa035.

Low, L.S., Chang, C.C., Tung, Y.P., & Yang, W.C. (2013). Marine science literacy and misconceptions among senior high school students. *Journal of Research in Education Sciences*, *58*(3), 51–83. DOI: 10.6209/JORIES.2013.

Lucrezi, S., Esfehani, M.H., Ferretti, E., & Cerrano, C. (2019). The effects of stakeholder education and capacity building in marine protected areas: A case study from southern Mozambique. *Marine Policy*, *108*, 103645. DOI: 10.1016/j.marpol.2019.103645.

Marroni, E.V., & Asmus, M.L. (2013). Historical antecedents and local governance in the process of public policies building for coastal zone of Brazil. *Ocean & Coastal Management*, *76*, 30–37. DOI: 10.1016/j.ocecoaman.2013.02.011.

McHugh, M., McCauley, V., Davison, K., Raine, R., & Grehan, A. (2020). Anchoring ocean literacy: Participatory iBook design within secondary science classrooms. *Technology, Pedagogy and Education*, *29*(1), 1–19. DOI: 10.1080/1475939X.2020.1715241.

McKinley, E., & Fletcher, S. (2010). Individual responsibility for the oceans? An evaluation of marine citizenship by UK marine practitioners. *Ocean & Coastal Management*, *53*(7), 379–384. DOI: 10.1016/j.ocecoaman.2010.04.012.

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

McPherson, K., Wright, T., & Tyedmers, P. (2018a). Examining the Nova Scotia science curriculum for international ocean literacy principles inclusion. *International Journal of Learning, Teaching and Educational Research*, *17*(11), 1–16. DOI: 10.26803/ijlter.17.11.1.

McPherson, K., Wright, T., & Tyedmers, P. (2018b). Challenges and prospects to the integration of ocean education into high school science courses in Nova Scotia. *Applied Environmental Education & Communication*, *19*(1), 1–12. DOI: 10.1080/1533015X.2018.1533439.

MMA. (2008). Macrodiagnóstico da zona costeira e marinha do Brasil. Ministério do Meio Ambiente. Retrieved September 01, 2021 from https://antigo.mma.gov.br/gestao-territorial/gerenciamento-costeiro/macrodiagnostico.html.

Mogias, A., Boubonari, T., Markos, A., & Kevrekidis, T. (2015). Greek pre-service teachers' knowledge of ocean sciences issues and attitudes toward ocean stewardship. *Journal of Environmental Education*, *46*(4), 251–270. DOI: 10.1080/00958964.2015.1050955.

Ocean Literacy Network (2020). *Ocean literacy*: The essential principles and fundamental concepts of ocean sciences for learners of all ages version 3. Retrieved September 01, 2021 from https://oceanliteracy.unesco.org/wp-content/uploads/2020/09/OceanLiteracyGuide_V3_2020-8x11-1.pdf.

Payne, D.L., & Zimmerman, T.D. (2010). Beyond terra firma: Bringing ocean and aquatic sciences to environmental and science teacher education. In B. Bodzin, S. Klein & S. Weaver (Eds.), *The inclusion of environmental education in science teacher education* (pp. 81–94). Netherlands: Springer.

Pazoto, C.E., Silva, E.P., Andrade, L.A.B., Favero, J.M., Alô, C.F.S., & Duarte, M.R. (2021). Ocean literacy, formal education, and governance: A diagnosis of Brazilian school curricula as a strategy to guide actions during the Ocean Decade and beyond. *Ocean and Coastal Research*, *69*(suppl 1), 1–14. DOI: 10.1590/2675-2824069.21008cep.

Pazoto, C.E., Silva, E.P., & Duarte, M.R. (2022). Ocean literacy in Brazilian school curricula: An opportunity to improve coastal management and address coastal risks? *Ocean & Coastal Management*, *219*, 106047. DOI: 10.1016/j.ocecoaman.2022.106047.

Pinheiro, A.B., & Silva, A.L.C. (2021). Environmental sensitivity analysis of the coast of Paraty (State of Rio de Janeiro, Brazil) to potential oil spills. *Revista Geográfica de América Central*, *66*(66), 133–164. DOI: 10.15359/rgac.66-1.6.

Ryabinin, V., Barbière, J., Haugan, P., Kullenberg, G., Smith, N., McLean, G., et al. (2019). The UN decade of ocean science for sustainable development. *Frontiers in Marine Science*, *6*, 470. DOI: 10.3389/fmars.2019.00470.

Santoro, F., Santin, S., Scowcroft, G., Fauville, G., & Tuddenham, P. (2017). *Ocean literacy for all - a toolkit*. Venice: Unesco.

Santos Municipal Law No. 3935 (2021). Retrieved February 01, 2023 from https://leismunicipais.com.br/a1/sp/s/santos/lei-ordinaria/2021/394/3935/lei-ordinaria-n-3935-2021-dispoe-sobre-a-promocao-da-cultura-oceanica-nas-instituicoes-publicas-e-da-outras-rovidencias?q=lei+da+cultura+oce%C3%A2nica.

Schoedinger, S., Tran, L.U., & Whitley, L. (2010). From the principles to the scope and sequence: A brief history of the ocean literacy campaign. *National Marine Electronics Association*, *3*, 3–7.

Souto, R.D., Polette, M., & Kampel, M. (2009). Evaluation of sustainability indicators for the coastal zone of Rio de Janeiro. *Brazil. Journal of Coastal Research*, *56*, 1311–1315.

Steel, B.S., Smith, C., Opsommer, L., Curiel, S., & Warner-Steel, R. (2005). Public ocean literacy in the United States. *Ocean & Coastal Management*, *48*(2), 97–114. DOI: 10.1016/j.ocecoaman.2005.01.002.

Stevens, R.A. (2021). Two Ocean Aquarium Academy: An introduction to ocean literacy programmes and a marine sciences curriculum. In K.C. Koutsopoulos & J.H. Stel (Eds.), *Ocean literacy: Understanding the ocean* (pp. 275–291). Switzerland: Springer Nature.

Tran, L.U., Payne, D.L., & Whitley, L. (2010). Research on learning and teaching ocean and aquatic sciences. *National Marine Electronics Association*, *3*, 22–26.

UNEP. (2006). Marine and coastal ecosystems and human wellbeing: A synthesis report based on the findings of the Millennium Ecosystem Assessment. United Nations Environment Programme. Retrieved September 01, 2021 https://www.unep.org/resources/report/marine-and-coastal-ecosystems-and-human-well-being-synthesis-report-based-findings

United Nations. (2018). Revised roadmap for the UN Decade of Ocean Science for Sustainable Development. Retrieved September 09, 2021 https://www.oceandecade.org/resource/44/REVISED-ROADMAP-FOR-THE-UN-DECADE–OF-OCEAN-SCIENCE-FOR-SUSTAINABLE-DEVELOPMENT.

Visbeck, M. (2018). Ocean science research is key for a sustainable future.Nature. *Communications*, *9*(1), 690. DOI: 10.1038/s41467-018-03158-3.

Wever, L., Glaser, M., Gorris, P., & Ferrol-Schulte, D. (2012). Decentralization and participation in integrated coastal management: Policy lessons from Brazil and Indonesia. *Ocean & Coastal Management*, *66*, 63–72. DOI: 10.1016/j.ocecoaman.2012.05.001.

Young, O.R., Osherenko, G., Ekstrom, J., Crowder, L.B., Ogden, J., Wilson, J.A., et al. (2007). Solving the crisis in ocean governance: Place-based management of marine ecosystems. *Environmental Science & Policy*, *49*(4), 20–32. DOI: 10.3200/ENVT.49.4.20-33.

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press

Carmen Edith Pazoto is a science teacher at state schools in Rio de Janeiro (Brazil) since 2008. She stands a degree in Marine Biology (2005, Universidade Federal Fluminense) and a Master in Zoology (2007, Museu Nacional- Universidade Federal do Rio de Janeiro). At presente she is finishing her doctorate studies in Marine Biology and Coastal Ecossystems at Universidade Federal Fluminense, Brazil (Programa de Pós-Graduação em Biologia Marinha e Ambientes Costeiros-PBMAC-UFF). She has been researching in the fields of Zoology, Marine Genetics and Evolution, her teaching efforts in formal education are concentrated on OL.

Michelle Rezende Duarte is a post-doctor at Laboratório de Genética Marinha e Evolução at Universidade Federal Fluminense-UFF (Brazil). She stands a Degree (2005), Masters (2007) and Doctorate (2016) on Marine Biology from UFF. Her research has been concentrated on Marine Genetics and Evolution of the Patterns of Biodiversity at Brazilian Coast in the last ten thousand years. She is expert in analysing data and meta-data in Ecology, Genetics and Evolution.

Edson Pereira Silva is a Lecturer at Universidade Federal Fluminense-UFF (Brazil). He stands a BSc in Marine Biology (1988, Universidade Federal do Rio de Janeiro-UFRJ), a Master in Genetics (1991, UFRJ) and a PhD in Population Genetics at University of Wales-Swansea (1998), where he also stayed for three years in a postdoctorate in Molecular Biology (2005–2008, Biotechnology and Biological Sciences Research Council, BBSRC, UK). His research work has been concentrated in Population Genetics of Marine Organisms, Evolution of Patterns of Biodiversity, Science Teaching and Epistemology.

Cite this article: Pazoto, C.E., Duarte, M.R., & Silva, E.P. (2023). Ocean literacy in Brazilian formal education: A tool for participative coastal management. *Australian Journal of Environmental Education* **39**, 507–521. https://doi.org/10.1017/aee.2023.12

https://doi.org/10.1017/aee.2023.12 Published online by Cambridge University Press