International Journal of Environmental Resilience Research and Science (IJERRS)
Revista Internacional Resiliência Ambiental Pesquisa e Ciência Sociedade 5.0 Resiliência Ambiental
ISSN 2675-3456

Ocean Literacy and Metabolic Rift Theory for Addressing the Effects of the Marine Ecological Crisis

Cultura Oceânica e Teoria da Falha Metabólica para o Enfrentamento dos Efeitos da Crise Ecológica no Mar

Luca Ribeiro Mendes Nicola[1]
https://orcid.org/0000-0002-3021-6553

Edson Pereira Silva[2]
https://orcid.org/0000-0002-3210-1127

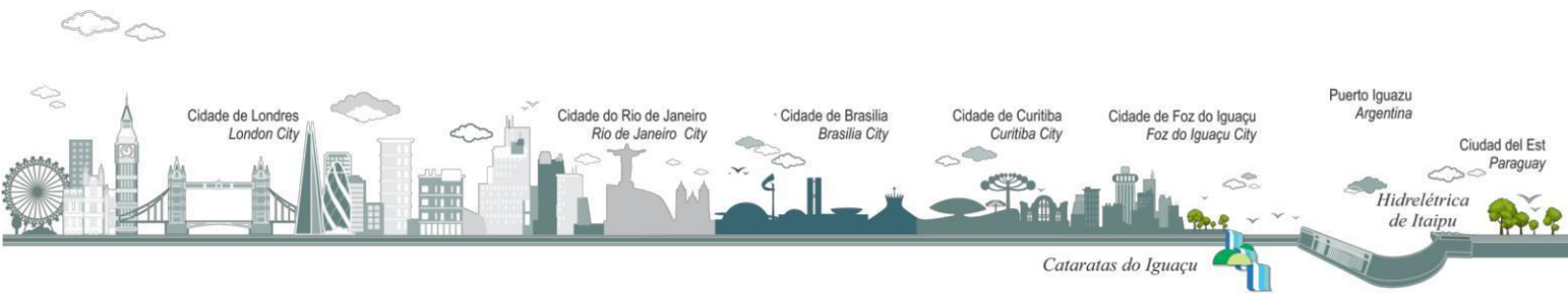
Carmen Edith Pazoto[3]
https://orcid.org/0000-0001-5724-5939

Michelle Rezende Duarte[4]
https://orcid.org/0000-0001-6175-7777

Abstract: Natural resources are used by society to produce goods and this proceeding mediated by human work which transforms nature. This process is called social metabolism and is expressed differently throughout history. In the capitalist mode of production, the exchange value subsumes use value and nature is modified on a scale beyond its reproduction capacity, establishing a metabolic rift that expands to different environments, including the marine. Ocean Literacy (OL) – understanding the human influence on the oceans and the influence of the oceans on human society – aims to contribute to overcoming the ecological crisis in the ocean, however, it is focused on a logic that ranges from the Enlightenment to post-modern perspectives. In the present work, it is proposed that OL incorporates the theory of metabolic rift in order to be able to organize society to face the challenges related to oceanic issues such as acidification, extinction of biodiversity, overfishing, etc. Finally, a case study of the "Onda Cultural'" (Cultural Wave) educational initiative of the "Laboratório de Genética Marinha e Evolução" (Marine Genetics and Evolution Laboratory) at Universidade Federal Fluminense (Rio de Janeiro, Brazil) is presented in its attempt to incorporate this theory into its OL practices and activities in public schools.
Key Words: Oceanic crisis. Metabolic rift. Social metabolism. Estate schools.

Resumo: A sociedade se utiliza dos recursos naturais para produção de bens de consumo e esta ação, mediada pelo trabalho, transforma a natureza. Este processo é chamado de metabolismo social

[1]MSc student at the Programa de Pós-graduação em Biologia Marinha e Ambientes Costeiros from the Universidade Federal Fluminense – UFF, working in the Laboratório de Genética Marinha e Evolução – LGME-UFF. E-mail: luca.nicola2233@gmail.com.
[2]Lecturer at the Departamento de Biologia Marinha, Universidade Federal Fluminense – UFF and head of the Laboratório de Genética Marinha e Evolução – LGME-UFF. E-mail: edsonpereirasilva@id.uff.br.
[3]Associated researcher at the Laboratório de Genética Marinha e Evolução – LGME-UFF. E-mail: carmenpazoto@gmail.com.
[4]Postdoctoral associated to the Pós-graduação em Biologia Marinha e Ambientes Costeiros from the Universidade Federal Fluminense – UFF, working in the Laboratório de Genética Marinha e Evolução – LGME-UFF. E-mail: michellerezendeduarte@yahoo.com.br.



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e se expressa de maneira distinta ao longo da história. No modo de produção capitalista, cujo objetivo é a extração de mais valor em detrimento do valor de uso, a natureza é modificada numa escala para além da sua capacidade de reprodução, estabelecendo uma falha metabólica que se expande para diversos ambientes, incluindo o marinho. A cultura oceânica (CO) – compreensão da influência da sociedade humana no oceano e a influência dos oceanos na sociedade humana – pretende contribuir para superação da crise ecológica neste ambiente, no entanto, é focada numa lógica que varia do iluminismo a perspectivas pós-modernas. No presente trabalho, é proposto que a CO incorpore a teoria da falha metabólica de modo a ser capaz de instrumentalizar a sociedade para os desafios relativos às questões oceânicas tais quais a acidificação, extinção da biodiversidade, sobrepesca etc. Por fim, um estudo de caso da iniciativa educacional *Onda Cultural* do Laboratório de Genética Marinha e Evolução da Universidade Federal Fluminense (Rio de Janeiro, Brasil) é apresentada na sua tentativa de incorporar esta teoria nas suas práticas e atividades de CO em escolas públicas.
Palavras-chave: Crise oceânica. Ruptura metabólica. Metabolismo social. Escolas públicas.

INTRODUCTION

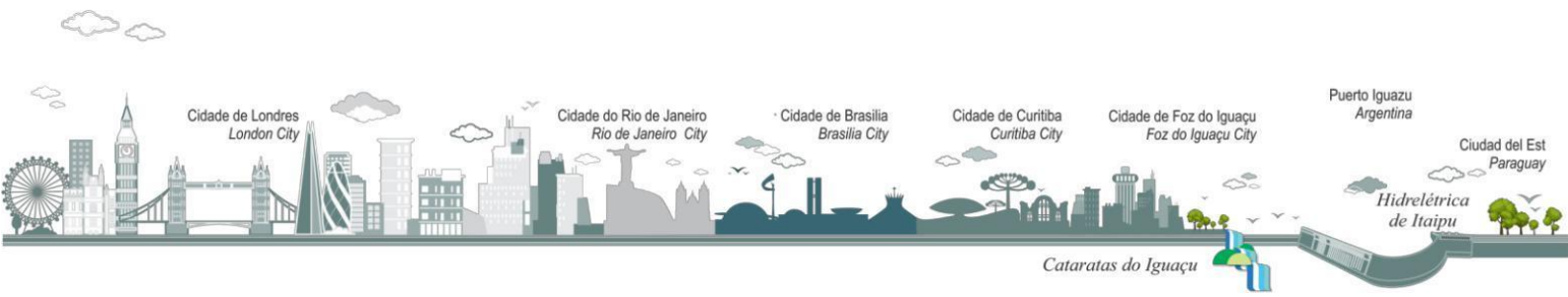
In Critias, Plato (428/429-347 BC) comments on the environmental condition of the mythological city of Atlantis:

> And at that period, in addition to their fine quality, lands produced plants in vast quantity. [...] what now remains compared with what then existed is like the skeleton of a sick man, all the fat and soft earth having wasted away, and only the bare framework of the land being left (PLATO, 2008, p. 108).

Despite the fictional aspect of the city mentioned, the philosopher's commentary likely addresses the impact of erosion in the cities of Ancient Greece. This phenomenon was attributed to deforestation for urban expansion and charcoal production, a primary energy source then (HUGHES, 2014). By 400 B.C., the environmental consequences of society-nature interactions were already evident. However, the initial effects of the so-called "ecological crisis" would only begin to be recognized in the 19th century with the nutritional depletion of arable soils (SAITO, 2021).

Ecological crisis

The German chemist Justus Von Liebig (1803-1873) linked soil depletion in various European and North American regions to the division between countryside and city, initiated

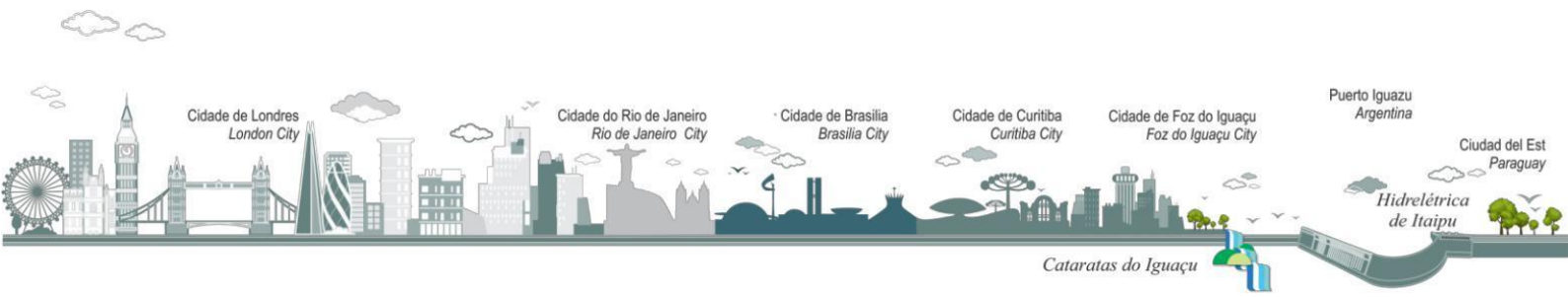


by enclosures in England and the subsequent privatization of rural access. He noted that this enduring situation prevented nutrients from food production from returning to the soil, trapping them in cities as waste (FOSTER, 2005). This continual waste production and disposal also emerged as an ecological issue, impacting urban water and air. Initially, the nutritional depletion crisis was addressed by importing guano (bird feces) from Peru, but from the 20th century onward, the focus shifted to producing artificial fertilizers.

The widespread use of artificial fertilizers overcame soil depletion issues, boosting agricultural productivity like never before in human history, thereby affecting population growth. However, fertilizer production and use released significant amounts of gases, including nitrous oxide and carbon dioxide (CAMPBELL *et al*., 2017). This increase in environmental carbon and nitrogen has led to issues such as anthropogenic eutrophication of water bodies, including oceans. Yet, it was the mid-20th century use of another agricultural additive, pesticides, that first sparked discussions about a potential ecological crisis.

In 1962, Rachel Carson (1907-1964) published "Silent Spring", depicting a spring without bird songs due to deaths from the trophic magnification of dichlorodiphenyltrichloroethane (DDT) use on monocultures in the United States of America (CARSON, 1962). While prior studies linked DDT to non-human organism mortality, Carson's book synthesized these incidents, suggesting an ecological crisis involving soil, river, ocean, and living being contamination, plus the emergence of pesticide-resistant pests (EPSTEIN, 2014). Despite facing U.S. chemical industry backlash, her book became a cornerstone in solidifying the U.S. conservation movement.

Conservationism aims for rational use of natural resources to preserve them for future generations, focusing on mitigating the various impacts of human activity on the environment (CRUZ *et al.*, 2016). Although present in the U.S. since the late 19th century, conservationism gained significant momentum after the impact of Carson's book, leading to a major victory in the 1970s with the establishment of the Environmental Protection Agency. This agency has been a key regulator of policies affecting environmental exploitation, notably issuing technical reports that led to the 1972 DDT-based pesticide use ban (EPSTEIN, 2014). By influencing legislation and scientific research, conservationism addressed the



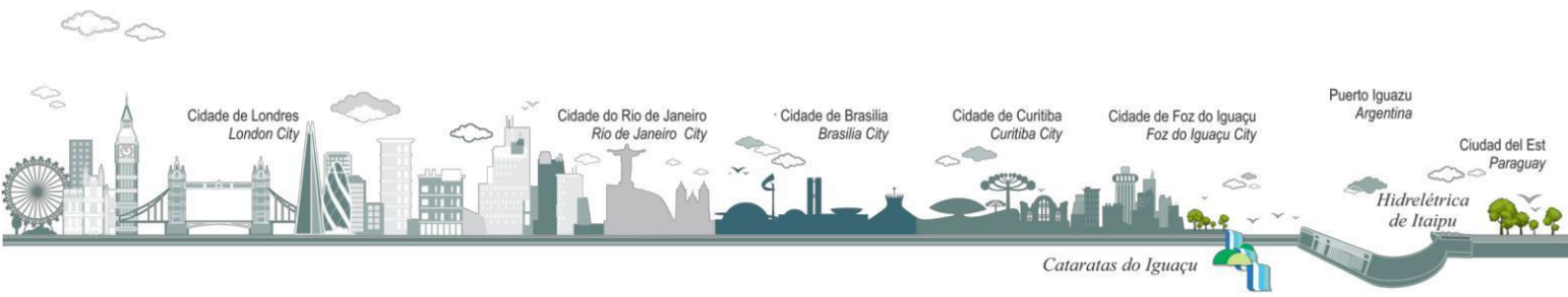
ecological issues arising from the interplay between society and nature, yet it was not alone. In contrast, ecologism focuses on addressing the root causes of the ecological crisis.

Ecologism took root in the 1970s, influenced by various social movements increasingly engaged in environmental debates, including counterculture, feminism, and anarchism (SILVA & ANDRADE, 2012). Notably diverse, ecologism includes strands informed by Marxism, which link the ecological crisis to capitalist production and its value accumulation. The challenge to the status quo by ecologism, particularly its Marxist currents, spurred an institutional response to the ecological crisis, starting with the Stockholm Conference.

Environmental Education

The 1972 United Nations Conference on the Human Environment in Stockholm acknowledged the link between environmental crisis and economic development, noting that environmental pressures varied among nations. It highlighted those underdeveloped countries, with rapid population growth and densely populated urban areas, were chiefly blamed for pollution threatening the planet. In contrast, developed nations were noted mainly for their high consumption rates leading to unsustainable resource exploitation (UNITED NATIONS, 1973). By discussing the environmental crisis without directly addressing its connection to capitalist production, the conference established an action plan aimed at aligning economic development with crisis mitigation, focusing on environmental education to raise awareness among citizens and businesses.

The proposed environmental education was to be grounded in science and technology, aiming for a proper understanding of environmental issues and the dissemination of knowledge about the ecological crisis. The principles that came to define environmental education were established from an international perspective at the following conferences: the Belgrade Meeting in 1975, the First Intergovernmental Conference on Environmental Education in Tbilisi in 1977, the Moscow Conference in 1987, the United Nations Conference on Environment and Development in Rio de Janeiro in 1992 (ECO-92), and the Thessaloniki Conference in 1997 (PEDRINI & SOUZA & SILVA, 2023). Throughout these conferences, a

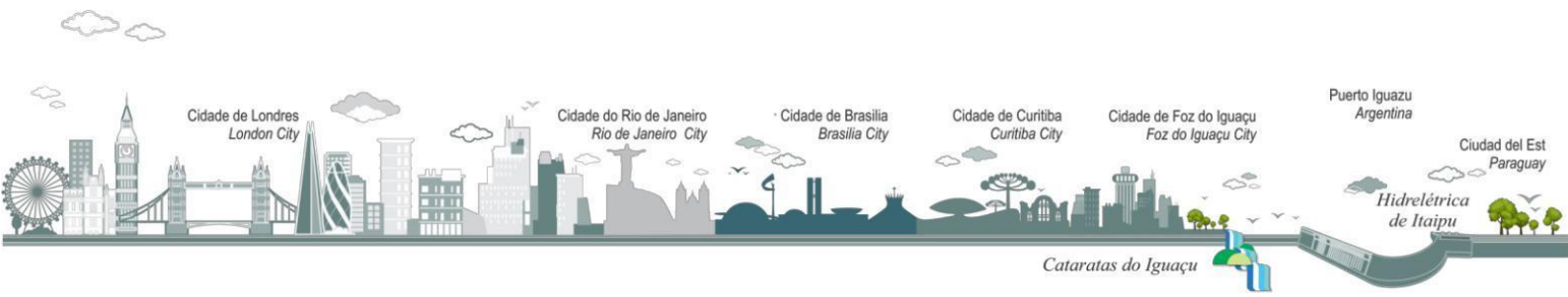


guideline was created stating that this type of education should occur across formal, non-formal, and informal settings for students and citizens (SILVA & ANDRADE, 2012). The goal was that such educational efforts would foster responsible behaviors and attitudes toward the environment. In Brazil, environmental education began in the mid-1970s and has since evolved, influenced by various theoretical perspectives. Despite its diversity, it can broadly be categorized into two main strands: conservative and critical.

The conservative field of environmental education focuses on educational processes addressing specific environmental issues without challenging the social structure causing the ecological crisis (LOUREIRO, 2003). For instance, the pragmatic trend in environmental education views the environment as a collection of natural resources and ecosystem services nearing depletion, advocating for behavioral shifts towards "sustainable consumption" to tackle issues like waste generation and greenhouse gas emissions (LAYRARGUES & LIMA, 2014). Another example within this field is the conservationist trend of emphasizing scientific literacy and aiming to solve environmental problems through the dissemination of scientifically accurate information (LAYRARGUES & LIMA, 2014).

Contrastingly, the critical field of environmental education challenges the conservative approach, arguing that merely spreading scientific knowledge is insufficient for fostering environmental responsibility, as it does not consider the reality of citizens engaged in educational practice (LOUREIRO, 2003). This approach promotes pedagogical practices that link education with social, economic, and political realms, aiming for social transformation.

For the Marxist trend within the critical field of environmental education, addressing environmental problems stemming from the ecological crisis necessitates a systemic approach (LAYRARGUES & LIMA, 2014). Educational practices in this area highlight dialogic education—often grounded in Paulo Freire's (1921-1997) pedagogical theory—engaging various societal segments to foster socio-political transformation. However, most environmental education experiences in Brazil, whether in the conservative or critical fields, have primarily focused on terrestrial environments (PAZOTO *et al.*, 2023a). To address this in a country with an extensive coastline like Brazil, the Coastal and Marine Environmental Education (EACM, in Portuguese) approach was developed.



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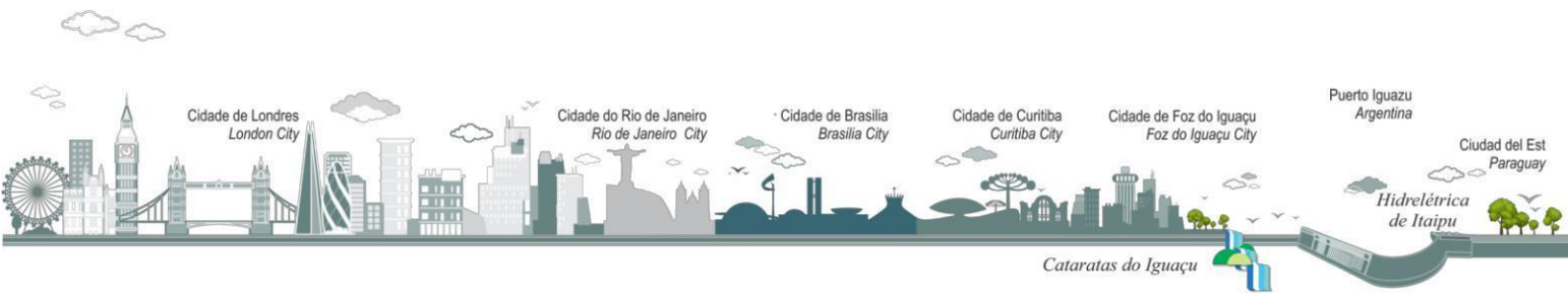
Coastal and Marine Environmental Education

Coastal and Marine Environmental Education (EACM) began to evolve in Brazil in the 1990s, aiming to explore public understanding of the environmental impacts caused by human activity on the ocean and to propose educational strategies to mitigate the ecological crisis in marine settings (PAZOTO *et al*., 2023a). However, these initiatives encountered a significant lack of public knowledge regarding the abiotic and biotic features of the marine environment (CEMBRA, 2011). In response, there were efforts to disseminate scientific knowledge about the ocean, utilizing charismatic marine species (such as the right whale and sea turtle) for outreach (PEDRINI, 2010), as well as information on marine ecological processes that directly influence terrestrial nutrient cycles (GHILARDI-LOPES *et al*., 2019). A fundamental assumption of EACM strategies was that spreading information about the marine environment would equip citizens with a critical perspective for making decisions that support a sustainable relationship with the ocean. In this respect, EACM shared a similar approach to the conservative field of environmental education.

On the other hand, EACM acknowledges that not all citizens have the same connection with the ocean and thus engages with diverse social groups (fishers, beachgoers, descendants of indigenous coastal communities that are commonly known as “caiçaras”, teachers, students, etc.), understanding their knowledge and interaction with marine environments (PEDRINI, 2010). Since a massive portion of the Brazilian population lives far from the ocean, EACM employs didactic strategies like videos, presentations, and virtual reality to foster empathy towards the sea among children and adults. Another crucial aspect of this educational approach is its interdisciplinary perspective (GHILARDI-LOPES *et al*., 2019), integrating knowledge from natural sciences (like Physics for ocean currents, Chemistry for water composition, and Biology for ecological relationships) and social sciences (such as Geography's study of anthropogenic impacts on the ocean and History's analysis of changing society-ocean exploitation). This multidisciplinary approach aligns EACM more closely with the critical field of environmental education.

EACM has advanced in Brazil through public higher education institutions and non-governmental organizations – NGOs (PAZOTO *et al*., 2023a). The publication of a book in



English (GHILARDI-LOPES & BERCHEZ, 2019) suggests that this approach to environmental education has gained some international traction. However, EACM still accounts for a small fraction of Brazilian academic output, with only 0.8% of theses and dissertations in the field of environmental education between the period of 1981 to 2020 being related to the ocean (PAZOTO et al., 2023a). Some of the reasons for this low representation of EACM are related to lack of funding, adequate infrastructure, specialized training, and the absence of laws integrating marine sciences into school curricula. Despite these issues, some long-term projects have been developed, for example the Projeto Tamarzinhos – “Tamarzinhos Project” – aimed at children and adolescents between 10 and 14 years old, consisting in a 1-year program where the participants are involved in environmental education activities coordinated by the Projeto Tamar – “Tamar Project” (PEDRINI *et al*., 2019). More recently, "Ocean Literacy”, another educational field addressing marine-related environmental issues, has emerged in Brazil.

Ocean Literacy

“Ocean literacy” is a movement that began in the United States in 2004, aimed at raising public awareness about the need for ocean conservation (PAZOTO *et al*., 2023b). At that time, marine scientists and educators determined that the inability to reverse the ecological crisis's effects on the ocean could be traced back to the public's lack of awareness about threats such as overfishing, acidification, warming waters, and trash accumulation affecting oceanic reproduction (SANTORO *et al*., 2020). In turn, this lack of awareness was linked to a scarcity of marine environment content in formal education curricula. The goal of ocean literacy was defined as understanding the ocean's influence on humans and vice versa (SCHOEDINGER *et al*., 2006), to be achieved through the movement's seven principles (Figure 1). Thus, “ocean literacy” aimed to incorporate topics into school curricula addressing these principles, fostering scientifically literate citizens in marine sciences to mitigate the marine impacts of the ecological crisis.

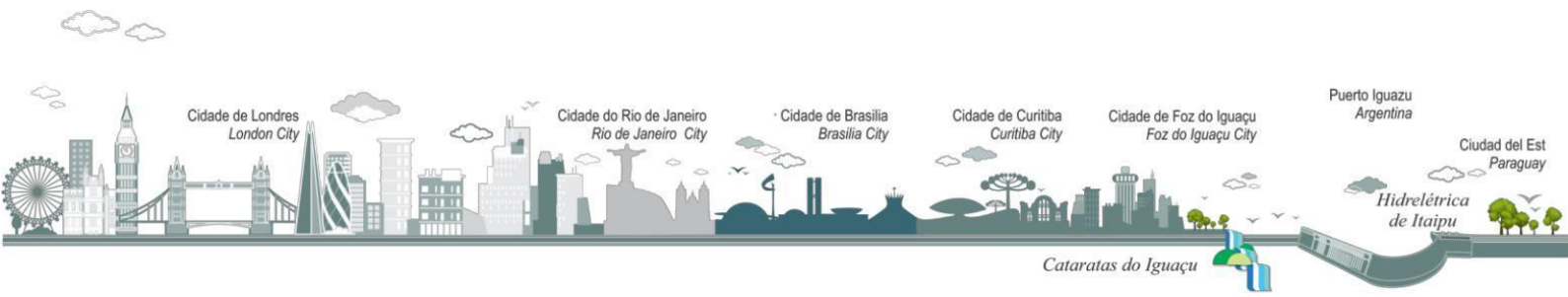


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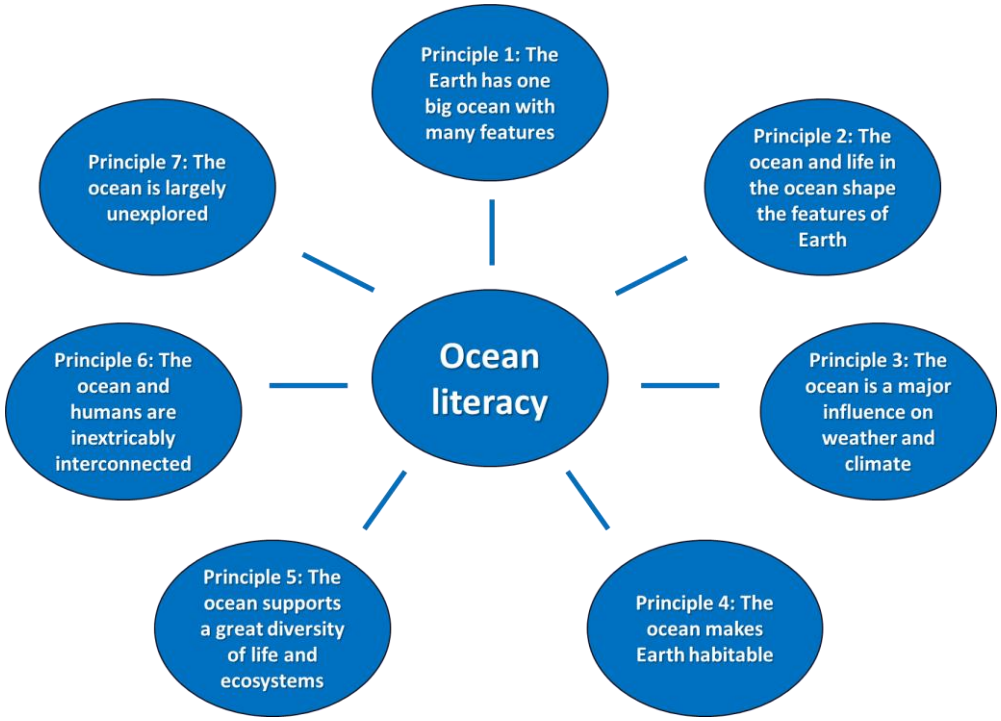
Figure 1 – Principles of the “Ocean Literacy” defined in the initial phase of the movement which guides the inclusion of marine environment subjects in formal education.



Source: Adapted from MAURÍCIO *et al.* (2021).

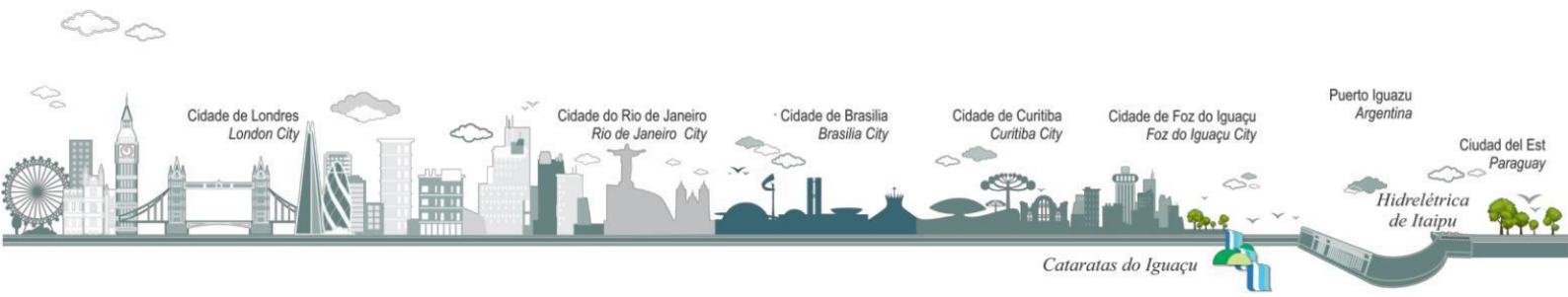
In the initial phase of “ocean literacy”, from its inception in 2004 to the end of the 2010s, various global scientist groups joined the movement, highlighting a critical assumption: the concept of literacy (MCKINLEY *et al*., 2023). This concept posited a direct relationship between knowledge about the marine environment's ecological crisis impacts and sustainable behavior. However, research revealed this relationship to be more complex, identifying additional influential factors on sustainable behavior adoption, such as individual awareness of the ocean's significance, emotional connection to the marine environment, the population's proximity to the ocean, and the communication methods used to disseminate marine environment information, among others (MCKINLEY *et al*., 2023). These findings led to a period of crisis within the movement during its first phase.

Challenging the initial phase’s notion that merely integrating ocean topics into formal education would suffice to alter citizens’ behaviors, the second phase of "ocean literacy"

argues for a broader engagement strategy to foster sustainable living habits, extending beyond curricular changes. This phase emphasizes encouraging actions and activities in informal and non-formal educational spaces, for instance, offering online courses, programming workshops, immersive experiences, artistic exhibitions, museum visits, public square discussions, and other similar activities. In this sense, it acknowledges the unique relationships various population segments have with the marine environment, influenced by factors like proximity to the ocean or the emotions the marine setting evokes (MCKINLEY *et al*., 2023). The transition in “ocean literacy” can be summarized as a shift from a focus on oceanic literacy or literacy to a broader concept of ocean “culture”, a term now adopted in Brazil (Cultura Oceânica) to encapsulate this evolved understanding of the movement (MAURICIO *et al*., 2021; PAZOTO *et al*., 2021b).

Recently, ocean literacy in this new perspective (culture) has gained international attention and support, notably from the UN through the Intergovernmental Oceanographic Commission's endorsement. This backing has spurred growth in scientific and academic output in the field, including the establishment of organizations across four continents focused on promoting ocean sciences, for example the European Marine Science Educators Association, Canadian Network for Ocean Education, Asian Marine Educators Association, and Latin American Ocean Education Network. Additionally, documents have been prepared to recommend the incorporation of ocean literacy principles and concepts into the curricula of countries (like the United States and Portugal) and administrative regions (such as the European Union). Ocean literacy's prominence is further highlighted by the proclamation of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030), during which the field is expected to serve as a scientific tool for behavioral change aimed at mitigating environmental impacts on the ocean.

Both ocean literacy and EACM emerged during a period when the impacts of Human actions on the ocean began manifesting across various societal aspects. For instance, the United Nations Food and Agriculture Organization (FAO) report on the state of fishery stocks highlighted the increasing demand for marine resources (FAO, 1995), and the "An Ocean Blueprint for the 21st Century" document from the U.S. Commission on Ocean Policy outlined various pollution forms affecting the country's estuarine water quality (U.S.



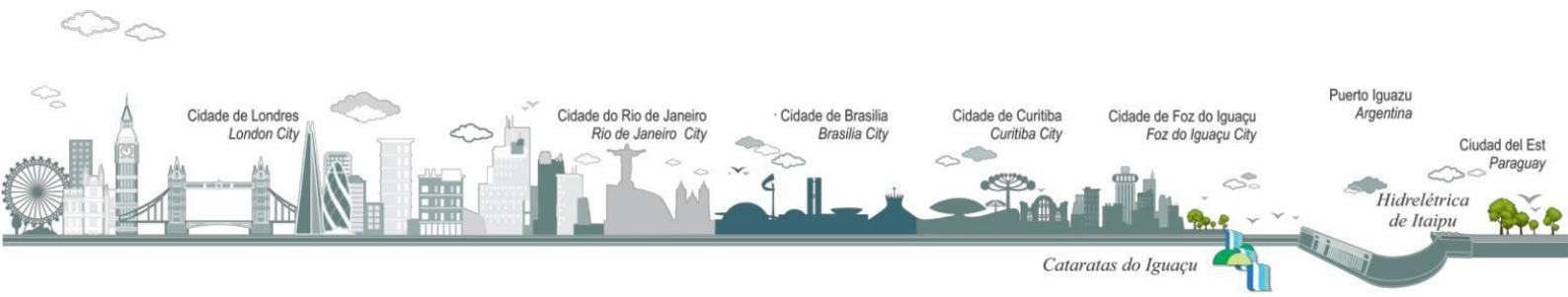
COMMISSION ON OCEAN POLICY, 2004). These developments led to a broader recognition of the extensive impact of Human actions on the marine environment, elucidating a range of environmental impacts that constitute an ecological crisis in the ocean.

ECOLOGICAL CRISIS IN THE OCEAN

Human activities, especially the rampant burning of fossil fuels, has caused Earth's average atmospheric temperature to rise significantly over the past 200 years. However, the shift from using the term 'global warming' to 'climate change' suggests that consequences are more complex than previously thought. For instance, the heat from gases released during fossil fuel combustion is absorbed by ocean water (with recorded increases in average marine water temperature since 1950), affecting even the ocean's abyssal regions (below 2000 meters depth) (CHENG *et al.*, 2022). This widespread distribution of heat throughout the ocean can lead to changes in marine currents, more frequent extreme weather events like heatwaves and marine storms, reduced water pH, and even alterations in the metabolic cycles of microorganisms. Thus, the drastic changes in oceanic thermal conditions result in a wide array of consequences, from the potential extinction of various species and shifts in biogeographical boundaries to ocean acidification, creating a current state of climate emergency.

Climate emergency

The flourishing of human societies was enabled by the relative environmental stability of the last 11,000 years during the Holocene epoch (ROCKSTRÖM *et al.*, 2009). Yet, from the 1980s onward, rising average temperatures signaled this stability was under threat, with deepening impacts from climate change (HEAD *et al.*, 2022). By the early 2000s, scientists had identified the processes essential for maintaining Earth's Holocene environmental conditions, outlining nine planetary boundaries: climate change, ocean acidification, stratospheric ozone depletion, biogeochemical flows, atmospheric aerosol loading, freshwater use, land-system change, biodiversity loss, and chemical pollution (ROCKSTRÖM *et al.*, 2009). For each

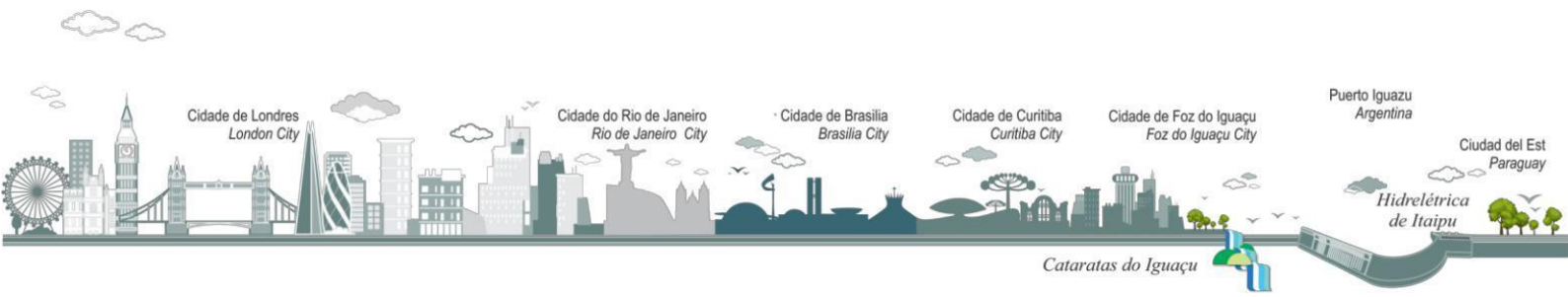


process, a disturbance limit was set; crossing these thresholds could lead to nonlinear changes in the biogeochemical cycles regulating the planet. By the early 21st century, the climate change boundary had been breached, signaling a climate emergency where, without significant greenhouse gas emission reductions, the impacts could become irreversible (ROCKSTRÖM *et al.*, 2009). The planetary boundaries model also considers the synergistic effects of boundary transgressions, suggesting that the climate crisis speeds up other limits being exceeded. Currently, six of the nine boundaries (climate change, biosphere integrity, land system change, freshwater use, biogeochemical flows, and novel entities – this last one formerly called chemical pollution) are surpassed, leading some to argue that Earth has entered a new geological epoch, the Anthropocene (RICHARDSON *et al.*, 2023).

Despite the geological debate on the term Anthropocene (HEAD *et al.*, 2022), there is no doubt that human actions are driving the climate crisis. Specifically, the emission of greenhouse gases like carbon dioxide and methane has led to increased average temperatures on land and in the oceans. Oceans have warmed rapidly, averaging 0.13°C per year since 1979, melting ice caps and raising sea levels. These rising temperatures are also weakening the North Atlantic Current, disrupting cycling and transport processes and reducing heat and nutrient distribution to Western European waters. Such nutrient depletion can adversely affect phytoplankton biomass, essential for the region's marine primary production, leading to ecological (changes in trophic chains) and economic (declines in fish stocks) impacts (BRIERLEY & KINGSFORD, 2009). Thus, there is a consensus that the current climate emergency is significantly affecting marine biodiversity (BROWN *et al.*, 2022).

Loss of marine biodiversity

Marine biodiversity is distributed throughout the ocean, but not uniformly, with greater species richness found in tropical and subtropical regions. The thermal stability of surface waters, ensured by the constant availability of sunlight, is a key factor supporting high species diversity in these areas. However, these ocean regions are most vulnerable to the impacts of rising water temperatures (BROWN *et al*., 2022). Climate change exacerbates water column stratification, where increasing temperature differences between surface and



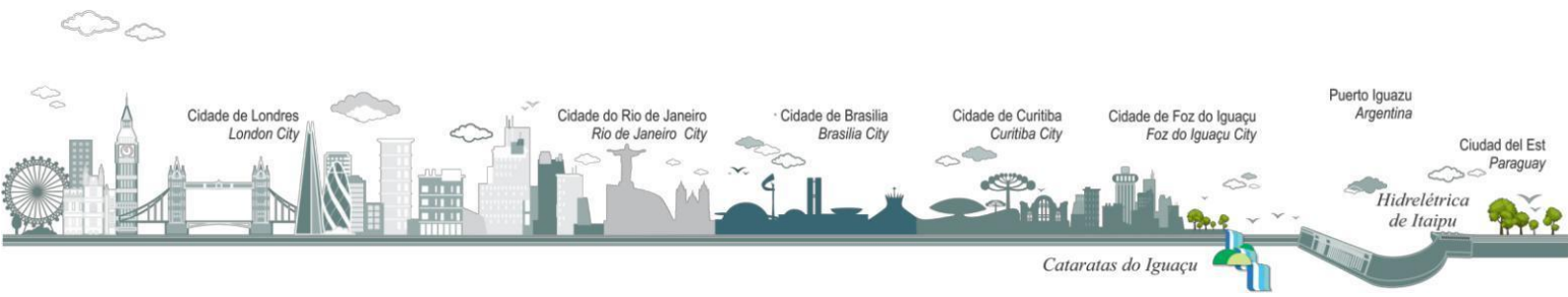
deeper waters hinder natural nutrient cycling processes. Consequently, photoautotrophic organisms experience reduced photosynthetic rates, diminishing the primary productivity of marine ecosystems. For organisms with limited migratory capabilities, such as coral reefs in the central regions of the Indian and Pacific Oceans, the main outcome is a significant population decline. However, for species capable of longer migratory journeys, warming waters lead to the colonization of new areas, a process known as bioinvasion.

Bioinvasion

Bioinvasion, or biological invasion, involves one or more species entering and establishing themselves in environments where they were not previously recorded, often causing changes in the local trophic web. Historically, marine organism bioinvasion is linked to maritime transport, either as fouling organisms or through ballast water, thus being transported from one location to another. For instance, the sun coral (*Tubastraea* spp.), originating from the Pacific and Indian Oceans, was introduced to the Brazilian coast, likely as a fouling organism on oil platforms. Since then, it has competed for space with native species, produced anti-fouling and anti-predatory chemical compounds, and altered the structure and function of native communities (VANÇATO *et al*., 2023). Additionally, physical changes in the marine environment, like water warming, can also trigger bioinvasion. An example is the diatom *Neodenticulata seminae*, native to the North Pacific, which established itself in the North Atlantic due to reduced ice cover and increased marine currents (CHAN *et al*., 2018). This kind of bioinvasion, driven by species distribution shifts due to rising water temperatures, is becoming increasingly common and is now a major source of bio-invasive species in some global regions (CHAN *et al*., 2018). Moreover, the increased presence of gases from fossil fuel combustion in the ocean impacts its pH level.

Ocean acidification

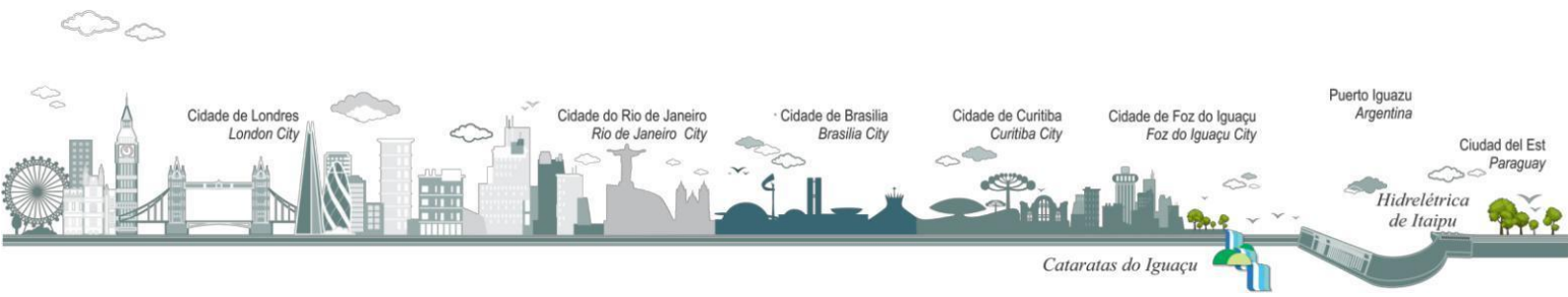
When carbon dioxide (CO_2) from fossil fuel combustion dissolves in the ocean, it reacts with water (H_2O) molecules to form carbonic acid and release hydrogen ions (H^+),



leading to a decrease in oceanic pH, a process known as ocean acidification (CORNWALL *et al*., 2021). The ocean's buffering system mobilizes carbonate ions $(CO)^{2-}$ to form bicarbonate, helping neutralize the pH. However, this acidification-buffering mechanism decreases the availability of carbonate ions crucial for calcification processes in marine organisms like the formation of exoskeletons. Consequently, starfish, corals, bivalves, crustaceans, and others produce less robust bodily structures, impairing their viability and survival, thus threatening marine biodiversity and industries that rely on healthy marine life (CORNWALL *et al*., 2021). Ocean acidification is particularly severe for ecosystems like coral reefs, where not just a single species, but an entire complex trophic chain faces the risk of extinction (CORNWALL *et al*., 2021). Furthermore, another human activity highlighting the ecological crisis in the ocean is overfishing.

Beyond the climate emergency

Undoubtedly, the climate emergency stems from burning fossil fuels, with atmospheric carbon dioxide concentrations jumping from 280 parts per million (the average level during the Holocene up until the start of the Industrial Revolution) to 420 parts per million (RIPPLE *et al.*, 2021). This value being much higher than the concentration of 350 parts per million that is considered necessary to establish a safe boundary for climate change (RICHARDSON et al., 2023). The heightened levels of gases like CO_2 in the atmosphere have destabilized the marine environment, endangering its physical and biological characteristics. Thus, the climate emergency is a key component of what constitutes the ecological crisis in the ocean. Moreover, due to the nonlinear way in which natural systems respond to disturbances, the affected ocean could exacerbate the climate emergency scenario. For example, as the ocean becomes more saturated with carbon dioxide, its role in thermal regulation, crucial for global climate stabilization, diminishes (BRIERLEY & KINGSFORD, 2009). However, the ocean's ecological crisis is not limited to the climate emergency; it also includes anthropogenic activities not linked to planetary temperature increases, such as overfishing.



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ISSN 2675-3456

The problem of overfishing

Fishing has a long history, dating back to the ancient indigenous coastal communities (sambaquieiros) culture as seen in archaeological records (ARRUDA *et al*., 2023). However, in the last century, fishing operations began to scale up significantly to meet the demands of a growing global market. This dramatic shift transformed traditional, small-scale fishing into giant industrial operations. Now, a single trawl can scoop up a staggering 400 kilograms of fish from the ocean floor. Initially, this large-scale fishing fueled catches and a booming fish trade. However, by the late 20th century, warning signs emerged – natural fish stocks were dwindling, catches plummeted for some species, and others vanished entirely. It was clear that this overfishing exceeded the reproductive capacities of fish populations (CLAUSEN & CLARK, 2005; SUMALIA & TAI, 2020), leading not just to industry alarms but also to potential marine ecological consequences like trophic web disintegration, as key biological community species were driven toward extinction. In response to the overfishing crisis, and more due to market dynamics than ecological concerns, aquaculture farms emerged in the latter half of the 20th century as a seemingly viable solution.

Aquaculture

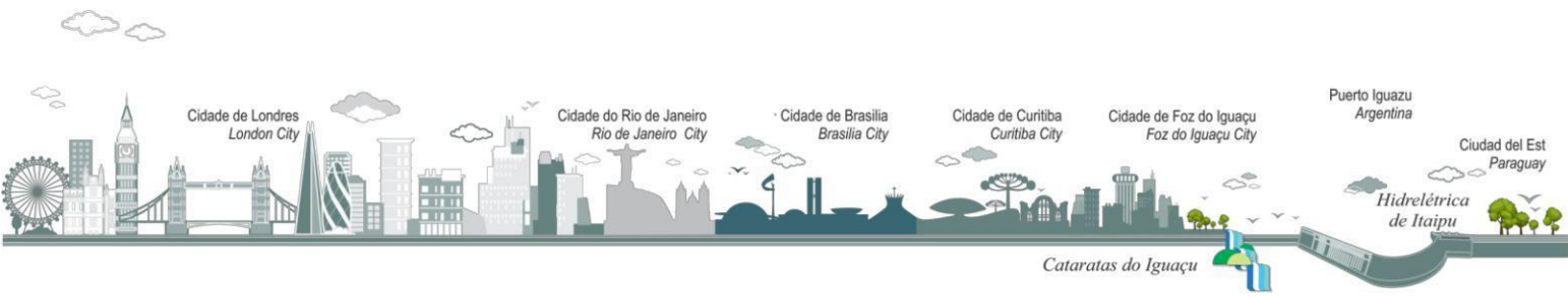
Aquaculture, the planned cultivation of marine organisms, is touted as a solution to meet market demands for seafood. Its appeal lies in two main aspects. The first is removing organisms from their natural environment and rearing them in artificial environments, controlling their life cycles. In controlled environments, science and technology can manipulate biological cycles for market needs, exemplified by the faster-growing, fattier transgenic salmon compared to wild *Salmo salar* (CLAUSEN & LONGO, 2012). The second is an intensification of production by such manipulation, especially on intensive production farms. This intensification allows for more goods to be produced in less time, addressing the rising demand for marine organisms.

While aquaculture is often promoted as a sustainable means of exploiting marine organisms, its high productivity necessitates a substantial and continuous input of resources.

In salmon farming, for example, the fish are fed a high-energy diet primarily composed of herring oil, which is derived from the capture of large quantities of lower trophic-level fish (LONGO & CLAUSEN, 2011). Thus, there is a reduction in the natural populations of herring that are preyed upon by wild salmon populations, establishing a resource competition between wild and farmed salmon. This competition can lead to the decline of natural salmon populations as their food sources are diminished. Additionally, to sustain captive populations with low genetic diversity and prevent high mortality rates, aquaculture often relies on antibiotics and fertilizers. However, not all these inputs are fully utilized, leading to their accumulation in the ocean, contributing to marine pollution, with potential effects including eutrophication of marine ecosystems and human health risks through biomagnification (CLAUSEN & CLARK, 2005). Thus, despite its advertised benefits, aquaculture hinders the establishment of a truly sustainable relationship with the ocean.

A civilizing challenge

The climate emergency is taking a toll on the ocean, leading to consequences like reduced marine biodiversity, bioinvasions, and ocean acidification. However, the full extent of these impacts remains largely unknown due to their immense complexity. Furthermore, the pervasive influence of the capitalist market in transforming marine resources such as fish into commodities – a process known as commodification – have led to overfishing on one hand and to pseudo-technical solutions like aquaculture on the other. Rather than ensuring the sustainability of natural resource exploitation, aquaculture acts like vast transgenic soybean farms at sea, thereby exacerbating the ecological crisis in the ocean. Consequently, the ocean's resilience is being compromised to the brink of a point of no return. The outcomes of such a phenomenon are unpredictable, but its cause is clear: contradictions inherent in the current organization of society and its relationship with nature. Thus, halting the effects of the climate emergency and unsustainable anthropogenic actions represents one of the great civilizational challenges for modern society in its relationship with the ocean.



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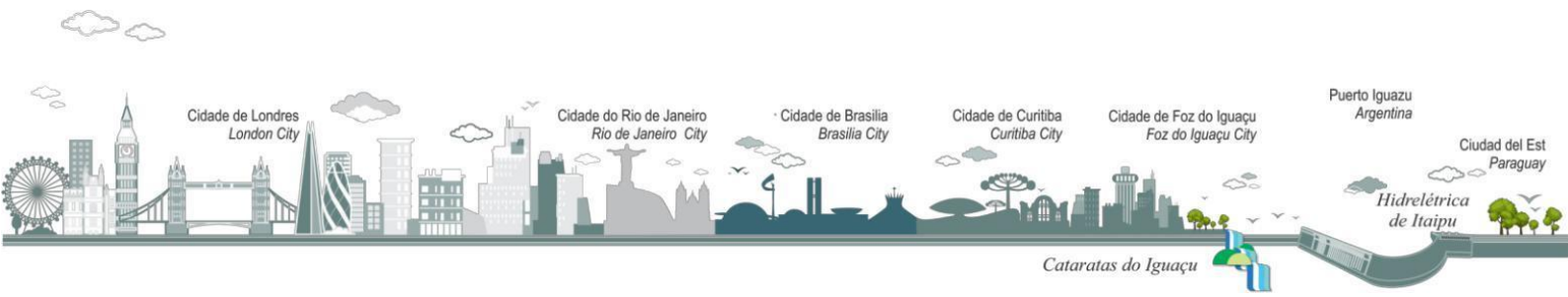
SOCIETY-OCEAN RELATIONSHIP

In this scenario, science and technology have been seen as both contributors to (according to degrowth theories) and a potential solution for (according to green capitalism theories) the ecological crisis.

Degrowth theories contend that economic growth, driven by the development of productive forces, lies at the root of the ecological crisis (KALLIS, 2011). Society's material progress comes at the expense of maintaining the ecological resources it depends on. According to degrowth advocates, current sciences and technologies, shaped by the economic growth imperative, are incapable of managing nature sustainably. The proposed solution would be degrowth or abandonment of practices and knowledge systems that drive economic expansion.

Conversely, green capitalism theories, also known as ecological modernization theories, acknowledge that economic growth initially harms the environment (YOUNG, 2000; FOX, 2023). However, it's argued that transitioning from an extractive to an industrial and eventually a post-industrial economy can mitigate these impacts using the same science and technology that caused them, thus paving the way for sustainable development. For instance, fossil fuels would be replaced by renewable energy sources like wind, solar, and geothermal power. In this sense, theories of ecological modernization propose that continued economic development and technological advancements (productive forces) will eventually lead to a point where environmental impacts become negligible due to highly efficient production tools (STUART *et al.*, 2020).

The perspective of Karl Marx (1818-1883) offers a nuanced understanding that transcends the dichotomy between degrowth and green capitalism, providing a framework for examining the relationship between society and the ocean through the lenses of science and technology. According to Marx, society-nature interaction constitutes a social metabolism. In the capitalist mode of production, this metabolism is dominated by exchange value, overshadowing the use value of goods (FOSTER, 2005). Consequently, the extraction of renewable resources exceeds the environment's recovery capacity, a contradiction known as



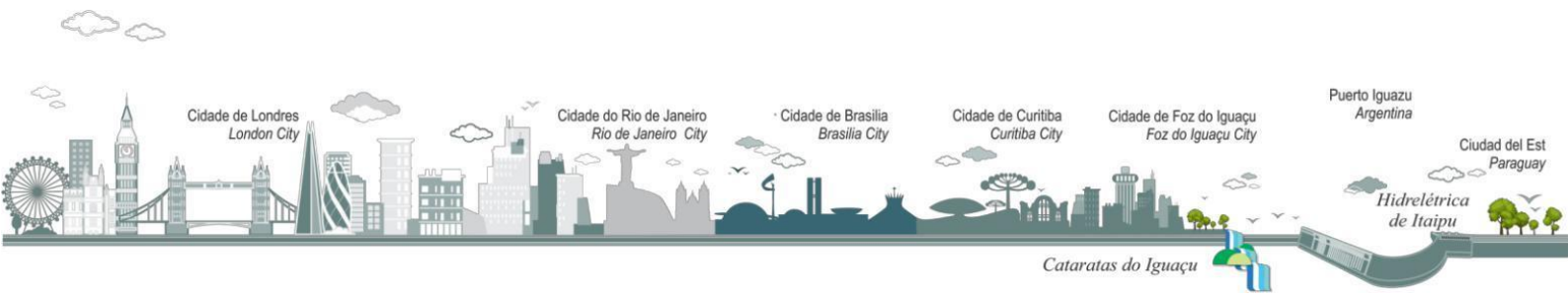
a metabolic rift, which is central to the ecological crisis in the modern and contemporary world (FOSTER & CLARK, 2020).

From this viewpoint, degrowth theorists overlook that the issue is not inherently with knowledge and technology themselves but with how they are used to expand the reproduction of commodities (GIBSON & EMPSON, 2023). Thus, the challenge is not to overcome material production per se but to address production driven by the commodity logic, which leads to the subjugation of natural needs to the capitalist accumulation cycle. Regarding green capitalism theories, their technocratic solutions fail to acknowledge the role that the current economic model plays in exacerbating the ecological crisis in the ocean.

The metabolic rift theory provides a praxis that can address the limitations of narrower theories like degrowth and green capitalism by (1) overcoming their antagonistic contradiction, (2) analyzing the issue from a structural standpoint, and (3) organizing the required actions to resolve the current ecological crisis. It is in this sense and with this intent that it is proposed here that the ocean literacy movement, which recently entered its second phase, needs to move to a third phase that incorporates the metabolic rift theory as the basis for its actions.

THE THIRD (NECESSARY) PHASE OF OCEAN LITERACY

In both its initial phase, aimed at overcoming "oceanic blindness", and its second phase focused on engaging various population segments and understanding their complex relationships with the ocean, the ocean literacy movement has not fully acknowledged that the metabolic interaction with the ocean is mediated by exchange value over use value, leading to the marine environment being subsumed by market logic that transforms it into a commodity. Therefore, it is crucial and urgent for the movement to transcend the enlightenment logic of the first phase, in which it is presupposed that society's problems are based on ignorance (darkness) and, therefore, all of them will be solved through knowledge (light). “Knowledge”, in this case, basically is referring to rationalism and scientific knowledge, ignoring that even they are subject to the contradictions and disputes characteristics of a class society. That said, it is also necessary to overcome the pluralistic perspective of the



second phase in which the relationship between capitalist society and the ocean is diluted in a set of individual relationships with the ocean. Thus, to overcome the two previous phases is necessary the adoption of a structural analysis of the ecological crisis in the ocean and in this way reaching a third phase to ocean literacy.

In this third phase, there is an understanding that while current scientific practices often facilitate intensive exploitation of marine resources, as seen in aquaculture farms, the same knowledge can be repurposed to sustainably manage marine resources through a free association of producers aiming to meet human needs. Furthermore, it acknowledges that the rampant exploitation of the ocean has a class dimension, where one class controls the means of production, dictating the commodification of the marine environment. Meanwhile, the class without access to these means is left with a relationship to the ocean defined by a lack of control over production processes, withstanding the worst of marine environmental impacts.

The depletion of bluefin tuna (*Thunnus thynnus*) populations in the Mediterranean Sea was not caused by local artisanal fishing, but by the emergence of large corporations catering to a global luxury market (LONGO & CLAUSEN, 2011). This industry not only led to the overfishing of bluefin tuna but also undermined traditional fishing methods. Moreover, the industrial activity expanded beyond the Mediterranean into the deep waters of the North Atlantic, complemented by the establishment of aquaculture farms.

The ecological theory grounded in historical-dialectical materialism offers a way to move beyond both developmentalist and catastrophist theories regarding the ocean's ecological crisis. This approach requires recognizing the class-based nature of marine exploitation, transcending the alienation inherent in scientific-technological development, and challenging individualistic ideologies (rooted in enlightenment principles) and pluralistic approaches (influenced by postmodern theories) that currently shape many educational initiatives aimed at halting ocean degradation. Figure 2 highlights the phases of the Ocean Literacy.

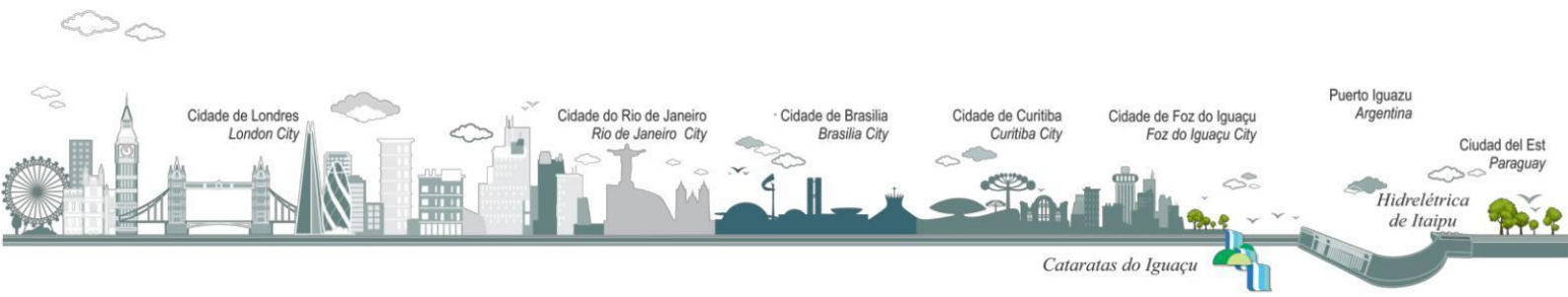


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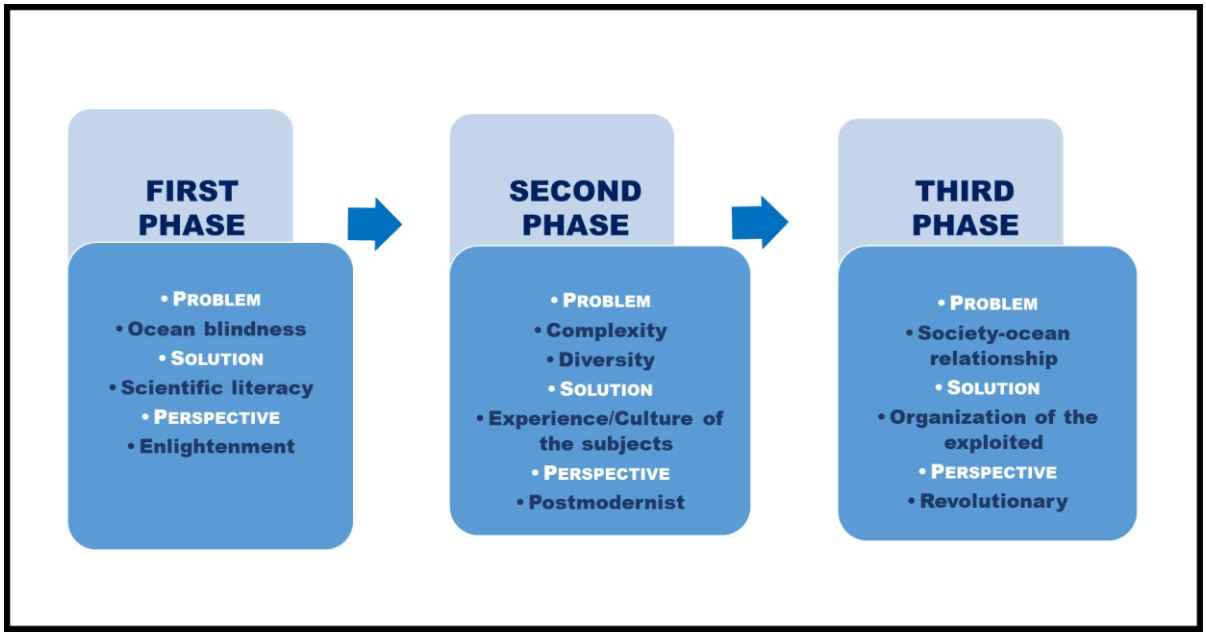
Figure 2 – Historical evolution of ocean literacy.

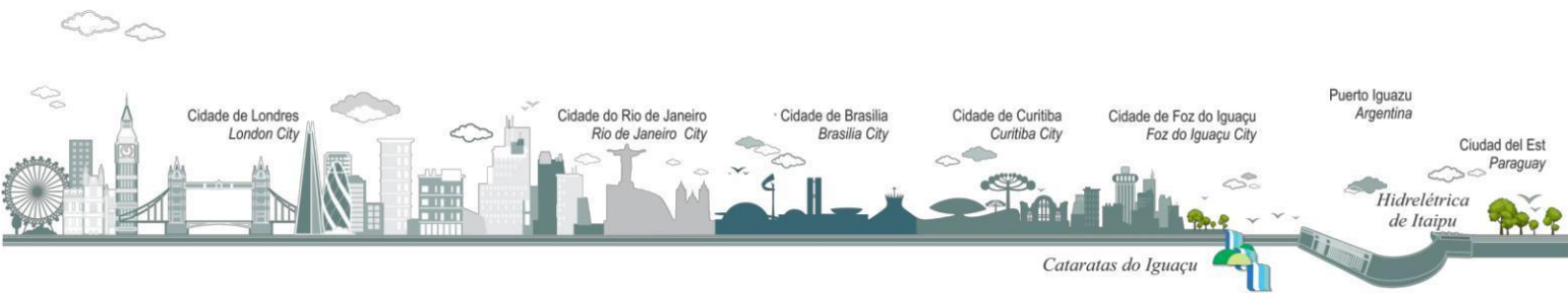


Source: The authors (2024).

ONDA CULTURAL (“CULTURAL WAVE”) IN SCHOOLS: A CASE STUDY

The "Onda Cultural" (https://ondaculturalnaescola.com.br/) project by Laboratório de Genética Marinha e Evolução – LGME (“Marine Genetics and Evolution Laboratory”) at the Universidade Federal Fluminense – UFF (“Fluminense Federal University”) aligns with the discussions above actively contributing to ocean literacy by critically addressing the society-nature relationship within the proposed third phase of ocean literacy. Their multifaceted approach includes engaging with public schools in Rio de Janeiro, maintaining a presence on social media, organizing public exhibitions, and contributing to scientific research.

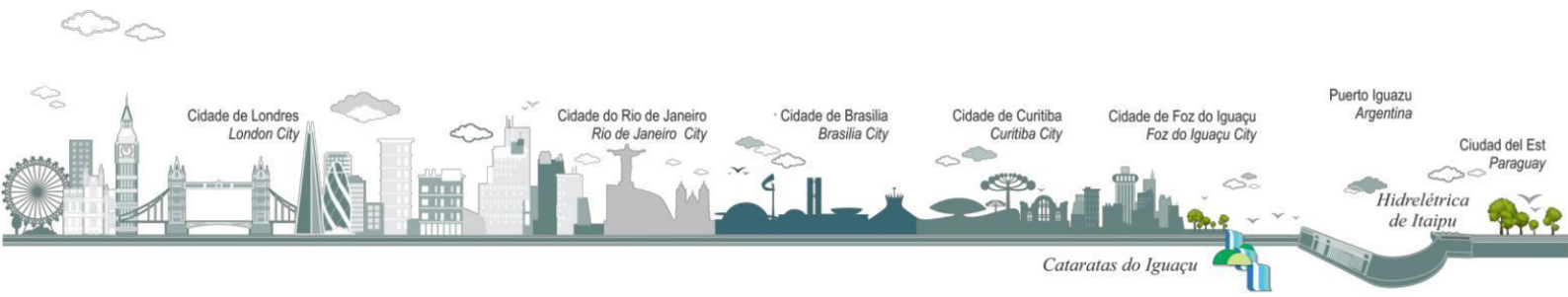
The "Onda Cultural" project engages with public schools in impoverished areas, focusing on students from low-income backgrounds. The initiative tailors its activities to the students' realities and their interactions with the marine environment, aiming to effect tangible changes in their immediate surroundings. The project employs various dimensions of ocean literacy as theoretical tools to achieve the goals set out for its third phase, including knowledge (highlighting that in a mode of production marked by class division, science and



technology are not shared equally, necessitating efforts to produce appropriate knowledge within working-class communities); communication (encouraging the dissemination of acquired and generated knowledge among peers at school, family, and community levels); perception (prompting students to reflect on their interactions with marine organisms, which are often influenced by commercial logic); attitude (moving beyond the idea of conscious consumption, like in waste management, to foster attitudes addressing how unequal wealth production contributes to the marine ecological crisis); and activism (introducing students to political organization in social, artistic, scientific, and cultural movements as means to transform society-ocean relations). Table 1 summarizes the actions that have been planned, developed, implemented, and evaluated with the students, which are illustrated in Figure 3.

Table 1 – Description of the actions performed in public schools, teaching strategies employed, and goals.

#	ACTION	TEACHING STRATEGY	GOAL
1	Natural and cultural heritage	Lecture	Knowledge Perception
2	Environmental waste	Lecture and practice	Attitude Communication
3	Marine and coastal organisms	Practice	Perception Communication
4	Lagoon, Beach, and Museum of Archaeology of Itaipu	Field trip	Attitude Activism
5	Observation of the material collected at the field trip	Practice	Knowledge Perception Attitude Activism
6	Reading Circle	Shared reading	Knowledge Perception Communication
7	Boa Viagem Beach, Museum of Contemporary Art, Janete Costa Museum	Field trip	Knowledge Perception Activism Attitude
8	Decomposition bottles	Practice	Knowledge Perception
9	Ocean acidification	Lecture and practice	Knowledge Perception Communication Attitude
10	Trail *Caminhos de Darwin* and Itaocaia Farm (Maricá, Rio de Janeiro)	Field trip	Knowledge Perception



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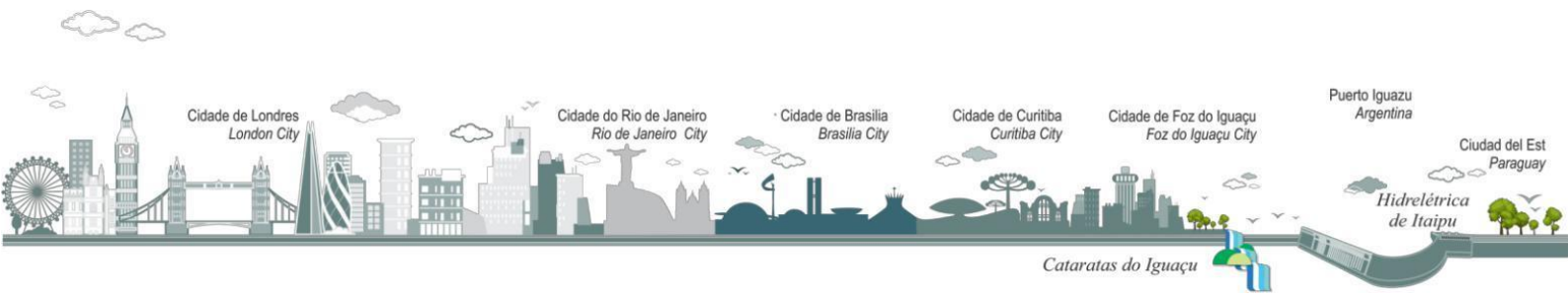
			Activism Attitude
11	Activity after the field trip	Practice	Knowledge Perception
12	Sediment formation	Lecture and practice	Knowledge Perception
13	Water properties	Lecture and practice	Knowledge Perception Communication
14	Movie: "*Ilha das Flores*"	Debate class	Attitude Communication
15	Coastal ecosystems	Lecture	Knowledge Communication
16	Tangram (Chinese geometric puzzle)	Practice	Perception
17	Sambaquis	Lecture and debate class	Knowledge Perception
18	Fact or fake?	Debate class	Knowledge Communication
19	Movie: "*Entremarés*"	Debate class	Perception Communication Attitude Activism
20	Fish morphology	Practice	Perception
21	Brainstorming *Baía de Guanabara*	Debate class	Knowledge Perception
22	Game "*Baía de Guanabara através do tempo*"	Practice	Knowledge Perception Attitude
23	Mock jury: environmentalists X workers of Guanabara Bay	Debate class	Knowledge Attitude Activism
24	Report on the cultural heritage visit	Practice	Knowledge Perception
25	Parque da Cidade, Jurujuba, and Aruanã Project	Field trip	Knowledge Perception Attitude Activism

Source: The authors (2024).

The "Onda Cultural" project utilizes social media (Facebook, https://www.facebook.com/lgme.uff/ and Instagram, https://www.instagram.com/lgme.uff/) for weekly posts to share its activities and underlying theories, recognizing these platforms' significant role in agitation and propaganda. Agitation here refers to spreading the project's guiding ideas and activities to as many people as possible, a strategy that has led to invitations to participate in various events, including the exhibition "*Futuros da Baía de*



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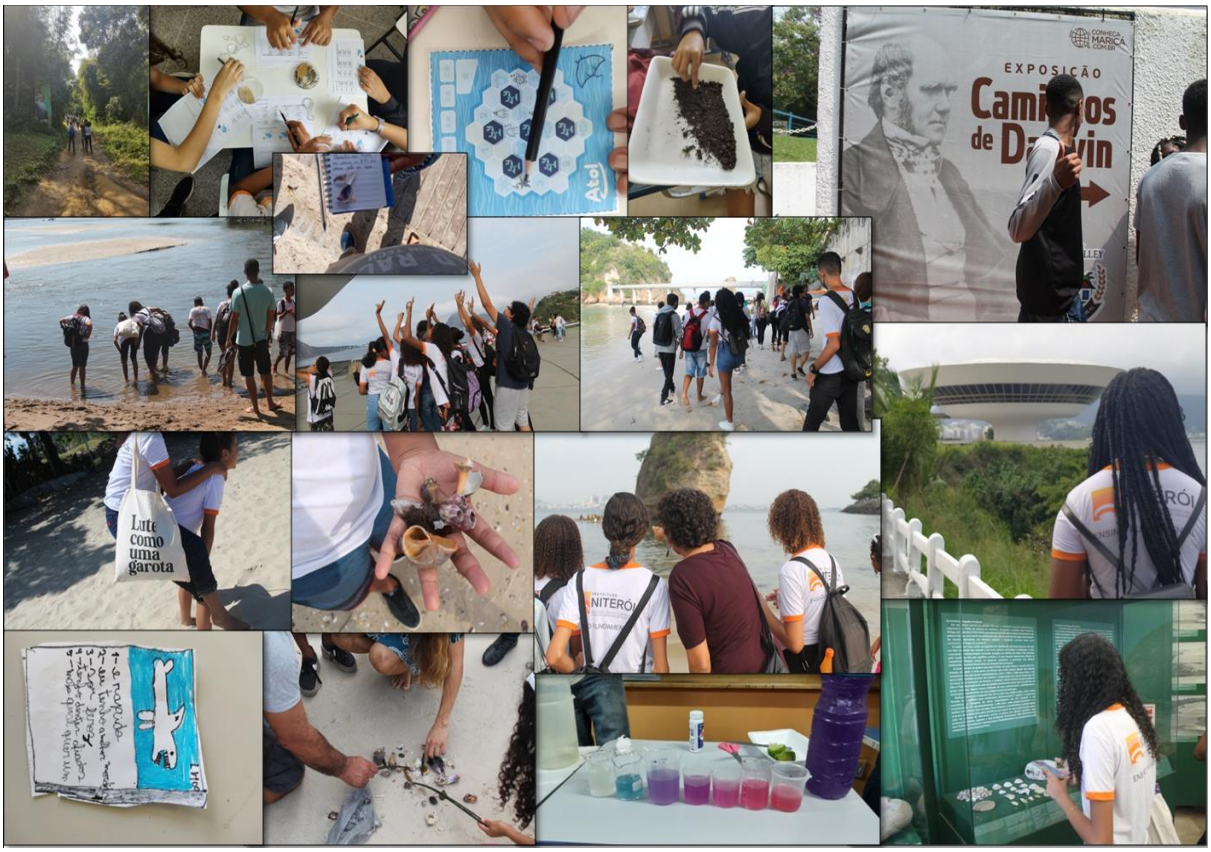
Guanabara-Inovação e Democracia Climática" in the Casa da Ciência ("House of Science") of the Universidade Federal do Rio de Janeiro – UFRJ ("Federal University of Rio de Janeiro"); the symposium "*Simpósio de Conservação, Aquicultura e Pesca*," organized by the Programa de Pós-Graduação em Ambientes Marinhos e Costeiros – PBMAC ("Post-Graduate Program in Marine Biology and Coastal Environments") at UFF; the Congress on Public Health and Human Training organized by the Sociedade Brasileira de Higiene e Saúde Pública ("Brazilian Society of Hygiene and Public Health"); and the III Symposium of Zoology in Rio de Janeiro State, organized by the Liga Acadêmica de Diversidade-UFF ("Academic Diversity League"), all in 2023. Therefore, this agitation carried out by the project seems to have achieved its goals.

Figure 3 – Photo panel showing some of the "Onda Cultural" actions in schools.



Source: The authors (2024).

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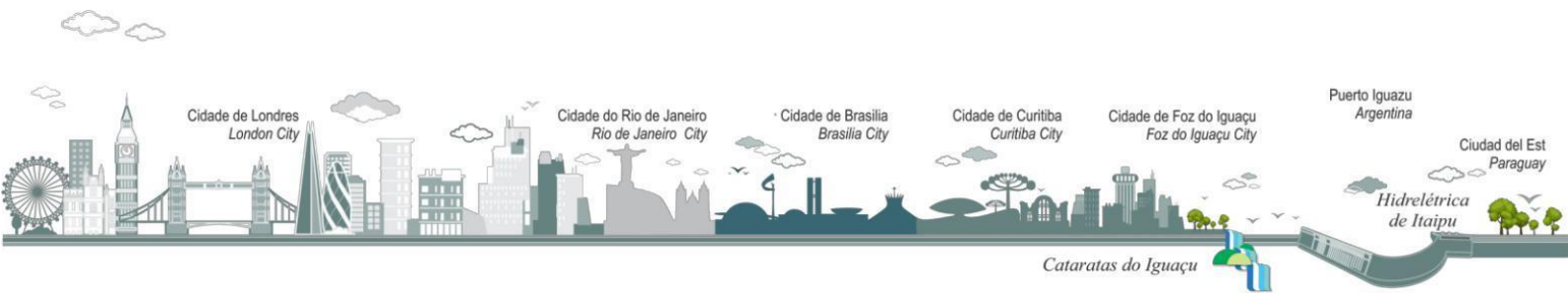
On the other hand, the project's propaganda efforts focus on the critical dissemination and discussion of concepts like degrowth, ecological modernization, green imperialism, speciesism, and conscious consumption. The goal is not merely to reach a wide audience but to educate individuals on understanding these issues through the lens of the metabolic rift theory. Table 2 categorizes and systematizes the major themes addressed in the project's social media agitation and propaganda efforts since 2022, accompanied by an example of its visual identity in Figure 4.

Table 2 – Main themes addressed in the social media agitation and propaganda efforts by the "Onda Cultural" project between 2022-2023.

CATEGORY	THEME	QUANTITY
Agitation	School activities	42
	Who does that?	14
	Reels	26
	Events	9
	Projects	1
	Sub-total	**91**
Propaganda	Theory	53
	Reviews	4
	Papers	11
	Dissertations and theses	1
	Sub-total	**69**
TOTAL		**161**

Source: By the authors using data published up to November 22 (2023).

The "Onda Cultural" project has been making concerted efforts to contribute to the bibliographic production of ocean literacy, a relatively nascent field in Brazil. This initial moment of ocean literacy in Brazil can be verified by the fact that only three papers had been published on ocean literacy by the year 2022. Since then, participants of the "Onda Cultural" project have added five more publications to the subject. Their publications have tackled several critical areas, such as reviewing the scope of activities in fields related to marine science research and knowledge dissemination in Brazil (PAZOTO *et al*., 2021a); analyzing



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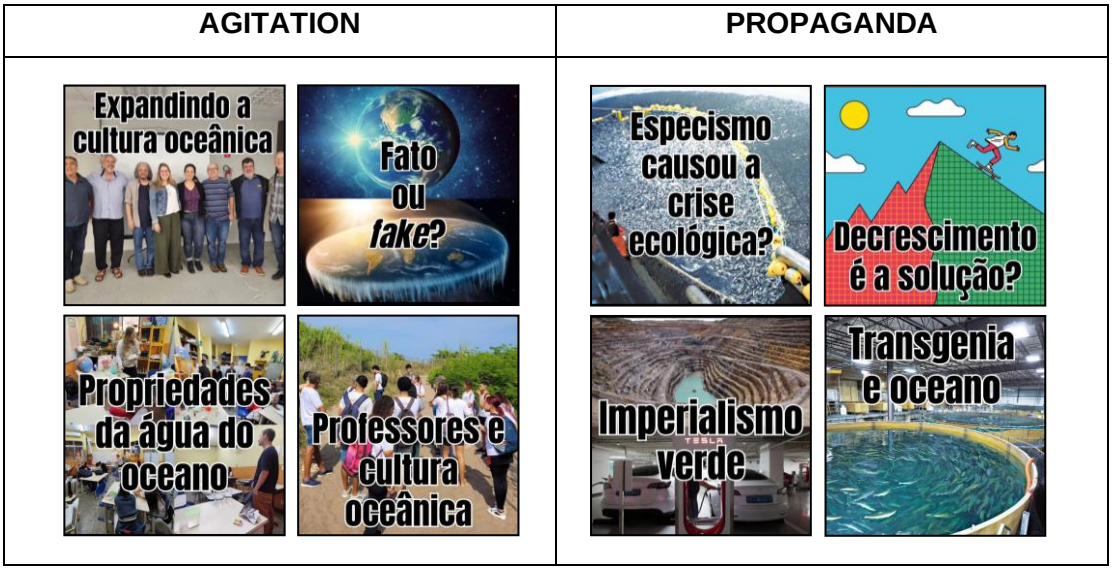
national curricula to understand how ocean literacy is integrated into education (PAZOTO *et al*., 2021a; PAZOTO *et al*., 2022; PAZOTO *et al.*, 2023b); exploring the challenges and prospects of teaching ocean literacy in Brazil from the teachers' viewpoint (PAZOTO *et al*., 2023c); and refining the set of activities developed and implemented by the project, detailing their evolution and impact (PAZOTO *et al*., 2023d).

Figure 4 – Examples of agitation and propaganda posts on social media.



Source: The authors (2024).

FINAL REMARKS

Ocean literacy has gained prominence in discussions about the marine ecological crisis, which is why this work aimed to outline the limitations of the movement's first two phases and propose what a necessary third phase might entail. This phase would move beyond individualistic or pluralistic approaches, addressing the root cause of the ocean's ecological crisis: the mode of production that prioritizes exchange value over use value. The "Onda Cultural" initiative embodies this perspective, engaging in activities at public schools in Rio de Janeiro, maintaining a social media presence, participating in academic events, and contributing to theoretical discourse.

ACKNOWLEDGEMENTS: The authors would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the master's scholarship granted to LRMN, enabling the present study. They also thank the Fundação Euclides da Cunha and the Fundação Municipal de Educação de Niterói for the financial support through the Programa de Desenvolvimento de Projetos Aplicados (PDPA), also granting a postdoctoral scholarship to MRD.

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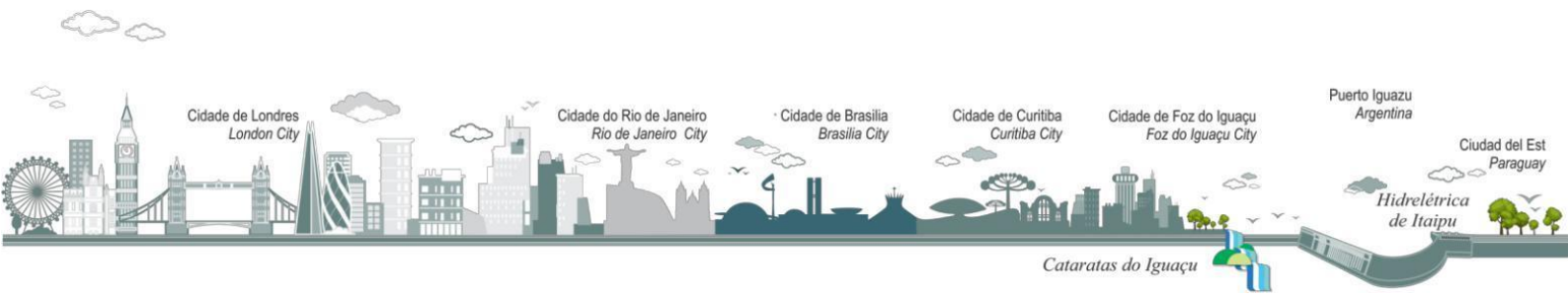

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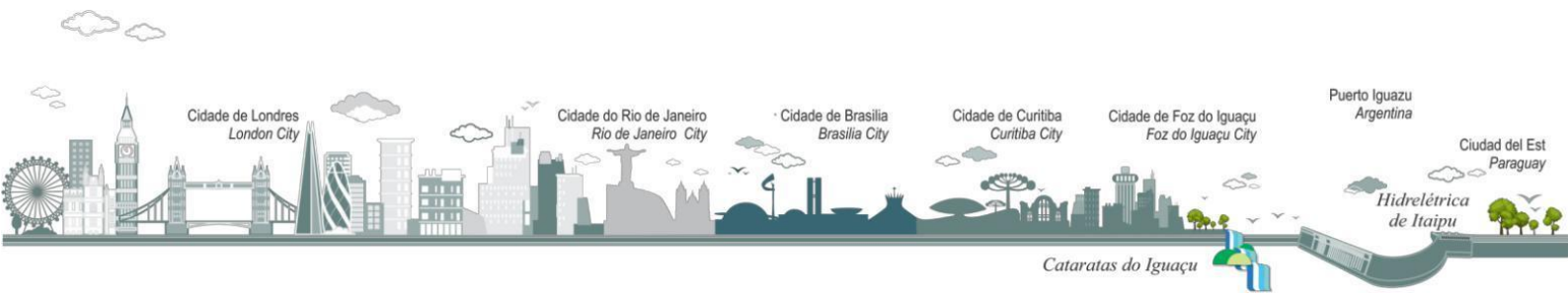

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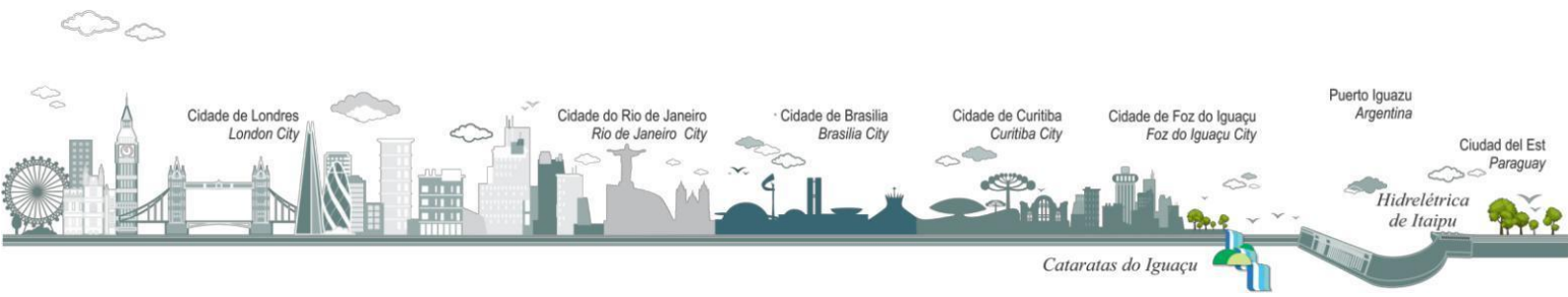

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