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EDITORIAL

Industrial ecology for the oceans

Human interaction with ocean resources has historically been challenging due to the difficulties that arise when a terrestrial species aims at becoming successful in a marine environment. Shipwrecks, for instance, have doomed coastal communities for centuries, and even today fishing is one of the deadliest sectors in the labor force. Similarly, human-induced marine environmental catastrophes, such as oil spills for instance (Trevors & Saier, 2010), have commonly been laborious to clean up due to the inherent difficulty of humans performing beyond terrestrial ecosystems.

Continued human population and economic growth since the beginning of the Industrial Revolution have exacerbated the need of human societies for mineral ores, fossil fuels, and other sources of energy, water, and food. This has led to the occupation of vast areas of terrestrial land, to the extent that humans now have a noticeable footprint in all the world's terrestrial biomes. In the world's oceans this same pattern has occurred at a slower pace throughout the decades, with fishing activities becoming more efficient with the arrival of steam vessels in the 1880s, diesel in the 20th century (Engelhard, 2008), and the incorporation of sophisticated detection systems turning ancestral coastal fishing activities into highly industrialized systems that land millions of metric tons of fish and other marine species annually (Fornshell & Tesei, 2013). Similarly, oil rigs spread quickly in the world's ocean to provide additional fossil fuel supplies for thirsty growing economies (Nyman, 2015), marine fright soared with the process of globalization (Mersin et al., 2019) with thousands of cargo vessels swarming the seas and, more recently, seabed mining has appeared in the public and private agenda as an alternative and lucrative sector to maintain the supply of metal ores in the technosphere (Levin et al., 2020).

This increased pressure of human activities on the ocean and its resources has translated into a series of environmental impacts that have affected marine conservation (Knowlton, 2021) and degraded vast areas of the ocean. However, it must be noted that not all environmental impacts affecting the ocean are located in the ocean itself, but rather are created by terrestrial activities. In this sense, nutrient loading linked to wastewater treatment plants, agriculture, and cattle ranching are responsible for vast dead zones generated in multiple coastal zones across the globe (Diaz & Rosenberg, 2008), and it is also mainly terrestrial activities that are responsible for the accumulation of plastic waste in the world's oceans (Beaumont et al., 2019).

Interestingly, many of these environmental impacts have only been analyzed in detail in recent years. For instance, marine plastic accumulation due to anthropogenic activities and its impacts on ecosystems and human health have only become a relevant field of research in the past decade after the Call for Action "Our Ocean, Our Future" of the Ocean Conference, organized by the United Nations in New York on June 5–9, 2017 (Sonnemann & Valdivia, 2017). In this context, although the focus of oceans-based research has traditionally been narrowly focused, researchers are recognizing the value of a wider, systems-based perspective with the aim of linking industrial uses with the environmental and resource impacts they engender. We argue that the field of industrial ecology is well-suited to fill that gap, as it is interdisciplinary in nature, rapidly growing, and has systems analysis at its core.

The current special issue of the Journal of Industrial Ecology, entitled "Industrial Ecology for the Oceans," explores all of the above-mentioned issues with the ultimate objective of catalyzing and compiling novel research regarding the use of industrial ecology in the world's oceans. A total of 24 articles were accepted for publication in the current special issue. These can be divided into five main topics: (i) fishing and aquaculture; (ii) shipping; (iii) ocean acidification; (iv) marine plastics; (v) nutrient flows; and (vi) seabed mining, and are described below.

1 | FISHING AND AQUACULTURE

Fishing and aquaculture constitute the biggest section of papers that are published in this special issue. Out of the 12 studies, 8 of them focus on applying a variety of life cycle methods to different case studies linked to the marine environment, 3 are linked to modeling fishing gear, and one final study analyzes the implications of including a circular economy perspective in the aquaculture sector.

In terms of life cycle assessment (LCA) studies, Ziegler et al. (2022) analyzed the greenhouse gas (GHG) emissions of a wide range of seafood products in Norway. Their results indicate that the fuel use intensity of most products has increased over the past decade in terms of fisheries, and that GHG emissions linked to salmon farming have also augmented due to a higher feed conversion ratio and more energy-intensive feeds. The authors also noted the very high emissions linked to the seafood products that are exported through airfreight. Cortés et al. (2022), Fernández-Ríos et al. (2022) and Wiloso et al. (2022) studied the environmental profile of three seafood products that are mainly consumed within the European Union. Cortés and colleagues (2022) analyzed the great scallop (*Pecten maximus*) fishery in Galicia (NW Spain), which showed a considerably high fuel use intensity value as compared to other seafood products landed in this important fishing region in Atlantic Europe. Fernández-Ríos et al. (2022) evaluated the environmental burdens linked to the capture, processing of albacore (*Thunnus alalunga*) in northern Spain. The results demonstrate that fuel combustion in the fishing stage remains as the main contributor to total environmental impact, and fuel use throughout the entire value chain is overwhelmingly the main contributor to impacts in most impact categories assessed. However, given the geographical characteristics of albacore fishing in the Cantabrian Sea, which is mostly coastal with short distances from the main fishing ports to the main fishing areas, implies that the fuel use intensity of this fleet is substantially lower than that of other albacore fisheries around the world (Parker et al., 2015). The study also included within the system boundaries the valorization, mainly for fishmeal production, of the organic waste flows derived from the processing of albacore into the final products delivered to consumers. The study by Wiloso et al. (2022) focused on the canning industry for Indonesian crab (*Portunus pelagicus*), which is mainly exported to Europe. The results, in line with previous studies in Europe (Hospido et al., 2006; Vázquez-Rowe et al., 2014), show that the tin used in the canning stage is the most impacting activity, although substantial reductions in environmental impact are shown for crabs caught with nets rather than traps. In all three cases, the results serve as important guidelines to implement improvement actions and sustainable practices in these fisheries.

A study by Almeida et al. (2022) provides an in-depth review of the impact of packaging materials in the overall impact of seafood products. Focused mainly on GHG emissions, the study highlights how paper- and plastic-based packaging materials tend to show substantially lower carbon footprint values than glass-, aluminum-, or tin-based packages. However, the authors also examine the differences in food loss and waste that different types of packaging may generate.

Pechsiri and Gröndahl (2022) provide a novel study on the environmental performance of wild *Nodularia spumigena* harvesting in the Baltic Sea to avoid the excessive spreading of algal blooms. For this, they limit the life cycle perspective to conducting an energy return on investment (EROI), in which they include the benefits of using the harvest for biogas or biofertilizer production.

In terms of aquaculture Philis et al. (2022) analyze an important setback that haunts the salmon farming sector, that is, the effects on salmon of ectoparasitic sea lice. In this sense, three different treatments against sea lice, which have historically been omitted in salmon-LCA studies, were compared. The results show that these treatments represent a relatively low contribution to the overall environmental impact of the salmon industry, although certain issues linked to fish welfare or ecosystem impacts may not be adequately represented in current metrics. Al Eissa et al. (2022) performed an environmental evaluation of three different shrimp production systems in Midwestern US and analyzed the effects of chaning the feed formulation. The results of this study, intended to support sustainable consumption policies for the most consumed seafood product in the US, suggest that the substitution of fishmeal by plant-based protein does not guarantee a reduction in environmental impacts.

A second group of papers in this block focus on the use of fishing gear in fishing operations. Kuczenski et al. (2022) acknowledge the importance of monitoring the damage that lost gear (also known as derelict gear) can generate in the ocean. In this context, they present an analytic framework to describe fishing gear use in the context of the environmental impacts linked to fishing activities in order to further understand how industrial fishing can impact the oceans through gear use and loss. In contrast, Nogueira et al. (2022) analyze the feasibility of implementing take-back schemes for fishing gears, comparable to that of beverage containers. A third study by Szostek and colleagues (2022) presents a quantitative method to determine how effective different fishing management scenarios (e.g., gear modification or substitution, fishing effort…) are in terms of mitigating the ecological effects linked to the seabed-penetrating fishing gear.

A final study in this block examines the challenges and opportunities that the aquaculture sector faces in the European Union regarding the promotion of circularity actions (Regueiro et al., 2022). The authors advocate for the integration of LCA decision-making frameworks with regulatory and economic aspects in order to foster an eco-innovative pathway to promote the competitiveness of the European aquaculture sector in the global market.

2 | SHIPPING

Two life cycle oriented studies on shipping are included in the special issue. On the one hand, Ankathi et al. (2022) calculate and analyze the GHG emissions associated with the global transportation of crude oil. GHG emission intensities were analyzed per country and a set of prospective scenarios, based on the projections provided by the International Energy Association, were modeled. Their results show that by 2050 if correct decarbonization policies are implemented, a reduction of 50% of well-to-hull emissions could be attained. On the other hand, Zhang et al. (2022) focus on cargo vessels to calculate the embodied energy and emissions associated with the material and fuel use of ship manufacturing. To do so, they considered an input–output life cycle approach to measure environmental impacts. The focus of the study is Chinese cargo vessels, and they provide a size-based range of GHG emission intensities.

A final study linked to shipping analyzes the influence of wind on shipping emissions in China in 2014 (Fu et al., 2022). The authors applied a speed modification model in which AIS information and hourly wind speed were integrated, showing that with this adjustment the emissions of all major air pollutants would rise significantly.

3 | OCEAN ACIDIFICATION

One single study, conducted by Scherer et al. (2022), delves into the problem of the increasing acidification in world oceans due to climate change. The authors acknowledge the lack of appropriate and updated LCA methods to analyze this environmental impact. Therefore, they propose a method to consider the negative effects of changes in ocean pH on the most affected species (i.e., those that have calcification processes). The characterization factors produced found important differences in terms of the sensitivity of calcifying species in different climate zones and, overall, they identified that 37% of marine species are highly vulnerable to ocean acidification. Hence, it seems plausible that ocean acidification may become a more relevant impact category in the near future.

4 | MARINE PLASTICS

Research in the field of marine plastics has increased exponentially in the past decade, although studies linking the plastic release to the ocean problem using industrial ecology are still scarce. In the current issue, however, six articles tackle the issue from several different perspectives. First, Baroth et al. (2022) perform a standing-stock survey to collect primary data on marine litter in India. In the study they compared a marine protected area with two areas of the littoral that are not protected, finding that non-protected areas presented, in general, higher levels of marine litter. Second, Cañado et al. (2022) focus on the circularity potential of marine plastic waste, by recuperating this waste to be used in 3D printing for new products in the marine industry. For this, they conduct an LCA study in which they compare marine plastic waste debris recuperation with virgin polymers (e.g., bio-based polyamide, polylactic acid, or polyhydroxybutyrate). The results obtained demonstrate that recuperated marine plastic performs better environmentally than the alternative polymers. A third study by Ita-Nagy and colleagues (2022) focused on the flows of plastic waste reaching the Pacific Ocean in Peru due to different terrestrial human activities. More specifically, the material flow analysis (MFA) methodology proposed takes into consideration possible natural and anthropogenic barriers (e.g., hydropower plants or mangroves) and boosters (e.g., uncontrolled open dumpsters or floods), in order to provide a more accurate estimation of the release of plastic waste from terrestrial sources in the context of emerging and developing countries.

Three additional studies in this block of papers are linked to LCA. However, unlike in Cañado et al. (2022), the focus is on developing characterization factors linked to the damage that marine plastic litter exerts on ecosystems. The importance of thesestudies is related to the fact that these types of damage are yet to be included in impact assessment (i.e., LCIA) when using LCA metrics (Woods et al., 2021). On the one hand, Lavoie et al. (2022) developed an effect factor to consider the physical impact on the biota of micro- and nanoplastics. On the other hand, Corella-Puertas et al. (2022) develop fate and characterization factors to model the impacts of two different types of microplastics in the marine environment: expanded polystyrene and tire and road wear particles. Both studies constitute a novel first step toward a future consolidation of plastic waste environmental impact and damage computation in LCA studies. An additional article by Pauna and Askham (2022) alerts of the fact that current LCA databases and assessment methods do not account for plastic polymers as potential pollutants in the environment. Hence, through an information flow analysis approach they identify the current data gaps that should be covered in the scientific community to improve microplastic accountability in LCA and risk assessment studies. Ecotoxicology and MFA were found to be two disciplines that should be analyzed further in combination with LCA studies with the aim of boosting the utility of LCA in decision-making when linked to plastic pollution.

5 | NUTRIENT FLOWS

Thomas et al. (2022) provide an LCA study in which they analyze the potential for nutrient uptake by a series of blue growth initiatives, which include kelp and mussel mariculture, among other activities. Using the eutrophication potential impact category, results suggest that these mariculture systems are capable of uptaking more nutrients than those they emit.

6 | SEABED MINING

Polymetallic nodules in the abyssal seafloor constitute an attractive source of certain critical metals, such as nickel or cobalt, given the depleting resources in terrestrial mining. Paulikas et al. (2022) analyzed waste streams of both nodule and terrestrial systems, identifying that metal production from nodules may produce less waste. Moreover, they suggest that this waste could be of lower severity, although further analysis should be performed in order to confirm these results in terms of sediment disruption.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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