



Marine litter as a tool to enhance ecological restoration

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ARTICLE INFO

Keywords:

Marine debris
Protected species
Deep sea
Corals
Bivalves

ABSTRACT

Marine litter represents an important threat for marine organisms and ecosystems and increasing efforts are dedicated to the removal of this source of impact. At the same time, marine litter is a substrate often colonized by species of conservation interest and therefore represents an overlooked resource for restoration. Here we conducted a literature survey to catalog the species colonizing marine litter. We found that many species, including some of high conservation interest, colonize the marine litter, particularly the abandoned fishing gears. Overall, we documented 41 macro- and megafaunal species, of which 88 % are currently protected by national and international laws or included in the IUCN Red List. The list of species includes either shallow-water and deep-sea corals, deep-sea bivalves, crustaceans, polychaetes and sponges. We propose the use of these species in marine ecosystem restoration along with a protocol to separate them from the litter, transfer them to aquaria, cultivate those most adaptable to captivity, and subsequently transplant them into impacted areas or use them in experimental studies. This approach has the advantage of replacing or minimizing the need to collect new organisms from pristine habitats. Since several organisms colonizing the marine litter belong to deep-sea species, this approach can promote active restoration interventions also in vulnerable deep-sea habitats. We conclude that, while preventing litter pollution is mandatory, marine debris removal can be an opportunity, through collaboration with the fishery sector, to develop a valuable strategy for the expansion of marine ecosystem restoration.

1. Introduction

Marine litter is defined as “any persistent, manufactured or processed solid material discarded, disposed or abandoned in the marine and coastal environment” (UNEP, 2009, 2016) and is now widely recognized as a major threat on marine life and ecosystems (Jambeck et al., 2015; Canals et al., 2021; Woods et al., 2021). Most of the marine litter is composed of plastic items but can include a large variety of materials such as metals, rubber, paper, processed wood, glass and concrete (De LaTorre et al., 2023; Cau et al., 2024). All floating plastic items (estimated in 1.1–4.9 million tons globally) are destined to sink and accumulate on the seafloor (Eriksen et al., 2023) and, since most of

the world seafloor lies at depths >200 m, deep-sea sediments are now recognized as the main sink for marine litter, plastic and microplastics (Pham et al., 2014; Woodall et al., 2014; Angiolillo et al., 2015; Rizzo et al., 2022; Cau et al., 2024). The mass of marine macrolitter (large pieces of litter, typically larger than 2.5 cm) can outweigh animal biomass in trawl catches along abyssal seafloors (Carreras-Colom et al., 2024). It is well known that marine litter can damage corals, especially deriving from derelict fishing gears lost during trawling activities (Williams et al., 2020). Furthermore, plastic causes a reduction of growth capacity and alters the feeding behavior by entanglement or ingestion (Chapron et al., 2018). Marine litter, especially plastic can be also ingested by organisms living in the sediment such as meio and

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macrofaunal assemblages (Pinheiro et al., 2020; Corinaldesi et al., 2022), with negative consequences for the food webs and eventually on ecosystem health (Tuuri and Leterme, 2023). For these reasons, marine litter is one of the tasks of the Marine Strategy Framework Directive (Descriptor 10) and there are increasing efforts to remove the macro-litter from the marine environment before the plastic items are fragmented to micro- and nano-plastics or the contaminants associated to other materials are released in the environment. At the same time, it is also well known that any artificial object at sea is rapidly colonized by many species from algae to crustaceans, from bryozoans to mollusks and polychaetes (Póvoa et al., 2021).

While the negative impacts of marine litter are now well demonstrated, there are also some potential side effects. Among these, the fact that all artificial substrates, including macrolitter, are colonized by several sessile species that use them for their recruitment (e.g., Battaglia et al., 2019; Carugati et al., 2021).

One of the current challenges is the restoration of damaged deep-sea ecosystems (Da Ros et al., 2019), which is typically conducted transplanting organisms from a pristine area to the restoration sites (Manea et al., 2023; Danovaro et al., 2025). However, all approaches minimizing the collection of organisms from pristine habitats should be encouraged, either for corals, gorgonians or macroalgae (see Cardinale and Danovaro, 2024; Montseny et al., 2020; Marletta et al., 2024).

This paper aims at assessing the potential use of megafaunal organisms colonizing marine litter for habitats restoration. To achieve the goal, we carried out a literature survey to census the association of threatened/protected species with macrolitter, and we explored the possibility of using these positive interactions for habitat restoration.

This *Perspective* article is based on a literature survey conducted across marine habitats at a global spatial scale (i.e., worldwide) and over a broad temporal range. We considered the available scientific literature (i.e., papers in international journals, contributions to scientific congresses) carried out at the international, national, or regional level by scientific communities. The details of the methodology used are reported in the SOM. The search encompassed only marine habitats (spanning shallow intertidal to deep-sea habitats) and land-sea interface habitats (Fig. S1), and was restricted to the studies on marine macrolitter reporting the identification of the associated fauna.

2. How many megafaunal species are associated to marine litter?

The results of our survey indicate that overall, 41 macro-megafaunal species were identified in previous studies (Table 1; Fig. S2). Of these, 17 species (equivalent to 41 % of the total species number encountered on marine litter) are currently protected under existing regulations/agreements at both national and international level. Twelve species (29 %) are included in the IUCN Red List: 8 species are classified as Critically Endangered, Vulnerable, Endangered, Data Deficient or Near Threatened, while only 4 species are classified as Least Concern. Only 1 species is not listed by the IUCN. This means that, all sessile macro-megafaunal species encountered on marine litter, except one, are potentially targets for protection and conservation.

This census, however, has important limitations, as most of the studies do not provide a list of marine species associated with macrolitter. In addition, 76 % of available info on biodiversity associated with macrolitter comes from the Mediterranean Sea, which represents only 0.82 % of the ocean surface. Only 11 % of the available information comes from the Atlantic Ocean, 6.5 % from the Pacific Ocean, and 2 % from the Indian Ocean, Red Sea, Barents Sea and North Sea combined (Fig. S2). Finally, available data does not allow a robust analysis of the bathymetric patterns of species distribution, as macrolitter-associated biodiversity was investigated on samples collected at depths ranging from 2 to 3.271 m, while the average depth of the oceans is ca 3.750 (Danovaro et al., 2014).

3. Are any precious species associated to marine litter?

Despite the limited information available on macrolitter-associated biodiversity, the analysis of the species list reported here pointed out the presence of a large number of species of high potential interest for conservation and therefore potentially useful for future restoration interventions. Several precious deep-sea coral species, such as *Errina aspera* (Linnaeus, 1767), *Desmophyllum pertusum* (Linnaeus, 1758) and *Madrepora oculata* (Linnaeus, 1758), can colonize artificial objects such as plastic items and ropes (approximately 4 % of the items contain *D. pertusum*; Battaglia et al., 2019). Furthermore, deep-water corals have been widely reported to colonize long lines abandoned on rocky cliffs (Fabri et al., 2014; Tubau et al., 2015). The deep-water coral *Desmophyllum dianthus*, has been recovered not only from abandoned nets, shipwrecks (Roberts et al., 2003) and oil platform rigs (Fig. 1), but also from floating plastic bottles (Bergami et al., 2021).

Another known interaction between corals and macrolitter (both plastics and ropes) is represented by the red coral *Corallium rubrum* (Linnaeus, 1758) where 20 juvenile colonies have been observed on four litter items (Carugati et al., 2021). Furthermore, gorgonians such as *Paramuricea macrospina*, *P. clavata* and *Eunicella cavolinii* (least concern in the IUCN Red List - Table 1), are frequently recovered over marine macrolitter (e.g., fishing nets or large plastic/metal items; Angiolillo et al., 2015). Various other sessile cnidarians, such as alcyonaceans are similarly found over macrolitter, including several species of the genus *Alcyonium* such as *Alcyonium acaule* Marion, 1878, *Alcyonium palmatum* Pallas, 1766, *A. coralloides* Pallas 1766, especially over relict fishing devices (Angiolillo et al., 2015). These species are also included in the IUCN Red List, although in some cases are reported as “Data Deficient”, or as “Least Concern”.

Sponges have also been frequently reported on abandoned fishing gears in deep sea (Angiolillo et al., 2015). *Lycopodina hypogea* is a sponge protected by the Barcelona Convention that can be found in high abundance on plastic items (30 individuals on 10 cm²; Santfín et al., 2020), often in association with the calcareous sponge *Sycon raphanus* (Battaglia et al., 2019). The bivalve *Neopycnodonte cochlear* (Poli, 1795), a bioconstruction known to colonize abandoned fishing gears in deep sea, is present in 4.4 % of the macrolitter items (Fabri et al., 2014; Battaglia et al., 2019). This species creates pinnacles in the deep sea, which hosts a rich biodiversity (Cardone et al., 2020) and is protected by the Habitat Directive (habitat type 1170 ‘Reefs’; Fig. 2). The giant crustacean (balanid) *Pachylasma giganteum* (Philippi, 1836), protected by the Bern Convention and Barcellona Convention, is present in approximately 6 % of the abandoned fishing gears (Battaglia et al., 2019). The non-endangered *Megabalanus tulipiformis* (Philippi, 1836) is reported from 19 % of the same macrolitter items. Another protected species frequently reported on macrolitter is the polychaete *Sabellaria alveolata*, which builds calcareous tubes in tightly packed masses with a distinctive honeycomblike appearance that can be up to 50-cm thick and take the form of hummocks, sheets or more massive formations (Rech et al., 2018). This species is included in the Habitat Directive (92/43/EEC; habitat type 1170 ‘Reefs’).

3.1. Litter-associated megafauna as a tool to promote habitat restoration

The presence of species of conservation interest on artificial substrates can have important potential implications in habitat restoration. The use of “opportunity specimens” (e.g. coral colonies entrapped in fishing gears, coral fragments, stranded colonies, macroalgae and sponges) can provide an opportunity to promote habitat restoration without using specimens from pristine habitats as donors.

The organisms present on the macrolitter recovered during cleaning operation could follow different paths: a) can be reared in laboratory or b) can be released back to the natural environment. This approach could be performed in three main phases: i) collection of marine litter with associated specimens/colonies; ii) separation of organisms/colonies

Table 1
Conservation interest, protection level and legislation of the species associated with marine.

Higher taxa	Species	IUCN	Bern Convention: Appendix II Strictly protected fauna species	SPA/BD Protocol: Annex II Lists species (endangered/threatened)	Habitat Directive (Council Directive 92/43/EEC)	
Cnidarians						
<i>Octocorallia</i>	<i>Alcyonium acaule</i>	LC				
	<i>Alcyonium coralloides</i>	LC				
	<i>Alcyonium palmatum</i>	LC				
	<i>Anthopleura</i> sp.	NE				
	<i>Corallium rubrum</i>	EN				
	<i>Paragorgia arborea</i>	NT				
	<i>Paramuricea clavata</i>	VU				
	<i>Paramuricea macrospina</i>	DD				
	<i>Eunicella cavolinii</i>	NT				
	<i>Hexacorallia</i>	<i>Madrepora oculata</i>	EN		X	
<i>Desmophyllum dianthus</i>		LC		X		
<i>Desmophyllum pertusum</i>		VU				
<i>Parantipathes larix</i>		NT		X		
<i>Parazoanthus</i> sp.		NA				
<i>Savalia savaglia</i>		NT		X	X	
<i>Hydrozoa</i>	<i>Errina aspera</i>	NE	X	X		
Crustacea						
<i>Cirripedia</i>	<i>Astrospartus mediterraneus</i>	NE				
	<i>Amphibalanus amphitrite</i>	NE				
	<i>Amphibalanus improvisus</i>	NE				
	<i>Austrominius modestus</i>	NE				
	<i>Chthamalus stellatus</i>	NE				
	<i>Lepas anserifera</i>	NE				
	<i>Lepas pectinata</i>	NE				
	<i>Megabalanus tulipiformis</i>	NE				
	<i>Neocasta laevigata</i>	NE				
	<i>Pachylasma giganteum</i>	NE	X	X		
	<i>Perforatus perforatus</i>	NE				
	Mollusca					
	<i>Bivalvia</i>	<i>Isognomon nucleus</i>	NE			
<i>Magallana bilineata</i>		NE				
<i>Magallana gigas</i>		NE				
<i>Neopycnodonte cochlear</i>		NE			X	
<i>Ostrea</i> sp.		NE				
<i>Mytella strigata</i>		NE				
<i>Mytilus edulis</i>		NE				
<i>Mytilus galloprovincialis</i>		NE				
<i>Mytilus trossulus</i>		NE				
<i>Perna viridis</i>		NE				
<i>Saccostrea cucullata</i>	NE					
Spongia						
	<i>Lycopodina hypogea</i>	NE	X			
	<i>Sycon raphanus</i>	NE				
Annelida						
<i>Polychaeta</i>	<i>Sabellaria alveolata</i>	NE			X	

LC – Least Concern (Widespread and abundant; not at significant risk of extinction).

NT – Near Threatened (Close to qualifying for a threatened category in the near future).

VU – Vulnerable (Facing a high risk of extinction in the wild).

EN – Endangered (Facing a very high risk of extinction in the wild).

CR – Critically Endangered (Facing an extremely high risk of extinction in the wild).

EW – Extinct in the Wild (Known only to survive in captivity, or as a naturalized population outside its past range).

DD – Data Deficient (Not enough information to assess extinction risk).

NE – Not Evaluated (Species has not yet been assessed against the criteria).

NA: not available in the IUCN List.

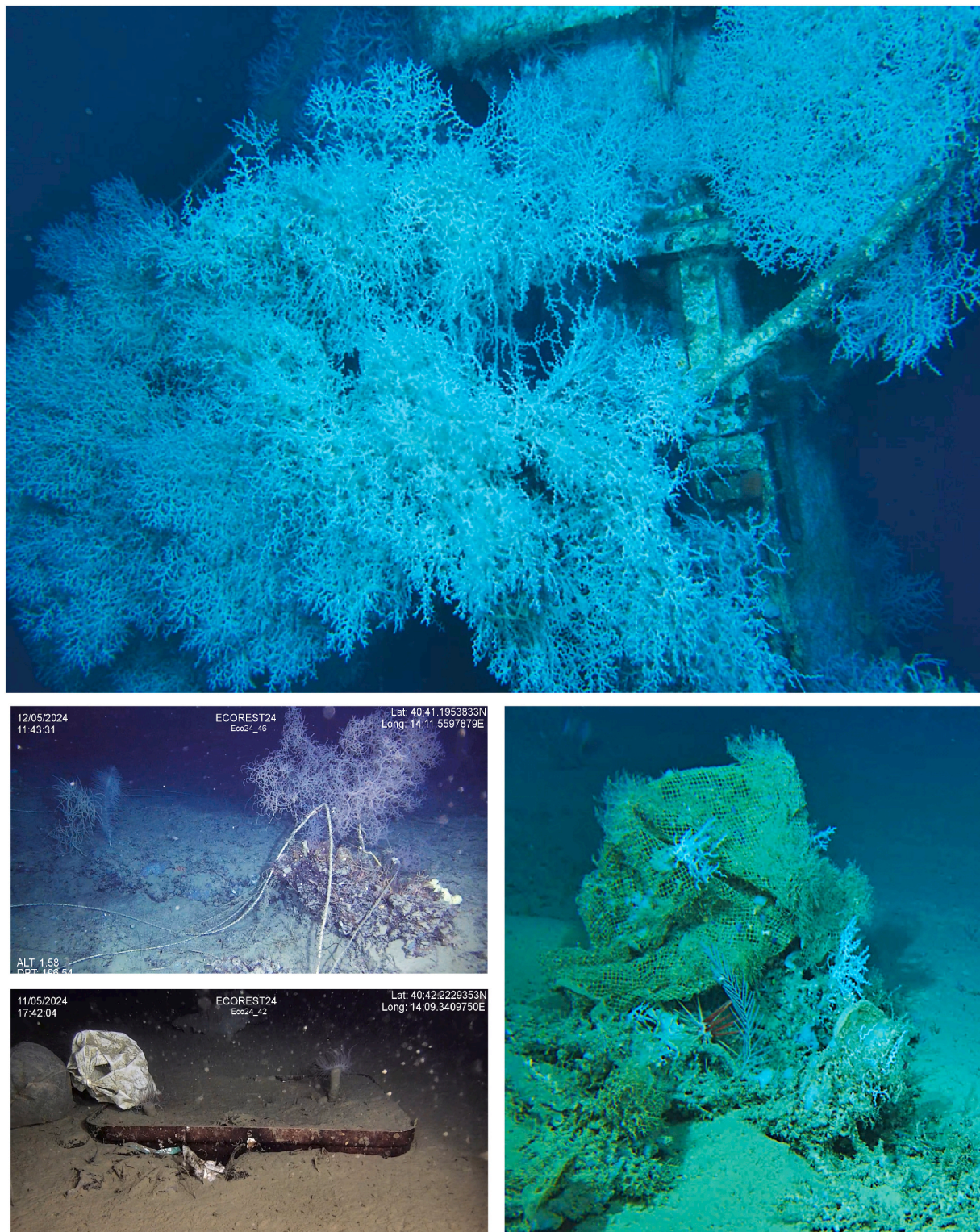


Fig. 1. Underwater images of deep-water corals and other megafaunal species growing on seafloor macrolitter in the Mediterranean Sea (images by Silvestro Greco and Simonepietro Canese: upper half and lower right; Federica Foglini: bottom and left panel).

from the litter; iii) attaching the organisms/colonies to an idoneous substrate (e.g., artificial substrate, rock, rubble) that can be located on the seafloor (Montseny et al., 2019, 2021). This approach is named ‘badminton method’ and has been successfully applied to gorgonians and corals attaching the bycatch to cobble supports and returning them back to seafloor directly from a boat (Montseny et al., 2021).

An alternative approach consists in transferring the corals in aquaria

or mesocosms to obtain new colonies. In this case the organisms can be reared or maintained till the availability of ship time. Both solutions allow to use organisms colonizing the marine litter without impacting the natural populations. With this method it is also possible obtain organisms for ornamental goals or for scientific investigations without harvesting natural populations.

There are several campaigns and ongoing projects (e.g., LIFE



Fig. 2. Example of the various species, including *Desmophyllum pertusum* growing on macro-litter and recovered by trawling (Image by Federica Foglini).

DREAM) dedicated to the marine litter removal starting from the derelict fishing gears and other types of litter (Gilman et al., 2022). If this was coupled with the separation of the species of interest from marine litter, the collection of specimens for ecological restoration could increase enormously. This can be done also by equipping the fishing vessels with aquaria. The identification of the target species can be done either providing training to the crew or by promoting the presence of a marine biologist onboard.

Although so far restoration efforts dealing with marine sponge have been based on cultured species, marine litter might represent a useful source of sponges that can be found abundant on artificial substrates (Bierwirth et al., 2022). Several species of bivalves (e.g., *Mytilus edulis*, *Mytilus galloprovincialis*, *Mytilus trossulus* and *Ostrea* spp.) are also frequently observed on marine litter but they are of lower interest for restoration purposes (Kotwicki et al., 2021; Rumbold et al., 2020) except possibly their contribution to oyster reefs' restoration (McCormick et al., 2024).

Since marine litter can remain on the seafloor for many years, this approach has the advantage to recover specimens that would require many years to reach the same maturity and reproduction potential.

Reducing and hampering the dumping of marine litter is and remains a priority, but the removal of macro-litter needs to be enforced to limit the current impacts of marine life. To implement this action, we need to establish a strong collaboration with fishermen and promote "Fishing for Litter" activities. Fishermen during their daily activity at sea recover tons of marine litter, with almost 80 % of it being plastic (UNEP, 2016). With the support of biologists onboard, or with appropriate training of fishermen, a large number of threatened organisms colonizing the marine litter could be collected and transferred to aquaria for subsequent transplantation. This collaboration will not only help remove harmful waste from the ocean but also support the restoration of marine ecosystems. This action could contribute to the achievement of the targets of the Marine Strategy Framework Directive (MSFD) for the waste

management chain (Gallegati et al., 2025).

4. Future perspectives

The results of this study indicate that marine litter, particularly large derelict items with solid surfaces (e.g., fishing gears), is colonized by several protected or endangered species of high ecological relevance. Most of these are habitat forming species, making their use in ecological restoration particularly valuable. One of the main limitations of deep-sea ecosystem restoration is the high cost of ship time and the limited accessibility to many deep-sea species. The use of species colonizing marine litter for habitat restoration can thus represent a relevant economic advantage in achieving future restoration targets. The United Nations Decade on Ecosystem Restoration (2021–2030) was launched to promote and expand active restoration interventions. Similarly, the European Nature Restoration Law (NRL) requires that restoration measures cover 20 % of the EU's land and sea areas by 2030, and that all ecosystems in need of restoration be restored by 2050. The measures proposed here are consistent with the Ocean Pact (European Commission, 2025) and its targets, as well as with the objectives of the Zero Pollution initiative, the Marine Strategy Framework Directive, and the Nature Restoration Law.

CRedit authorship contribution statement

Roberto Danovaro: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Ettore Nepote:** Writing – review & editing, Writing – original draft, Investigation, Data curation. **Cristina Gambi:** Writing – review & editing, Methodology, Investigation, Data curation. **Cinzia Corinaldesi:** Resources, Investigation. **Simonepietro Canese:** Resources, Investigation, Data curation. **Antonio Dell'Anno:** Writing – review & editing, Investigation. **Giorgio Castellan:** Writing – review &

editing, Resources. **Federica Foglini:** Writing – review & editing, Resources, Methodology, Investigation, Funding acquisition. **Silvestro Greco:** Writing – review & editing, Investigation, Funding acquisition.

Declaration of competing interest

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

Acknowledgements

This study was supported by the REDRESS project (Horizon Europe, Grant Agreement 101135492), LIFE21-NAT-IT-LIFE DREAM (Deep Reef restoration And litter removal in the Mediterranean sea) and the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.4—Call for tender no. 3138 of 16 December 2021, rectified by Decree no. 3175 of 18 December 2021 by the Italian Ministry of University and Research, funded by the European Union-NextGenerationEU, Award Number: project code CN_00000033, Concession Decree No. 1034, of 17 June 2022, adopted by the Italian Ministry of University and Research, Project title “National Biodiversity Future Center—NBFC”.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.marpolbul.2025.119019>.

Data availability

Data are uploaded SOM.

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