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Rajids ovipositing on marine litter: A potential threat to their survival

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ABSTRACT

Marine litter is a complex environmental issue threatening the well-being of multiple organisms. In the present study, we present an overlooked pathway by which marine litter interaction with certain ovigerous skates (Family: Rajidae) communities could compromise their survival. We propose that skates from the genus Sympterygia deposit their egg capsules on marine litter substrates by accident, which are then washed ashore still unhatched. We conducted 10 monitoring surveys on three beaches of La Libertad Region, on the north coast of Peru, looking for marine litter conglomerates to determine the presence of egg capsules. We registered a total of 75 marine litter conglomerates, containing 1595 egg capsules, out of which only 15.9 % were presumably hatched, and 15.8 % were still fresh. Fishing materials were identified as the main item in marine litter conglomerates. We conclude that this behavior could contribute to the decline of Sympterygia communities, although further research is needed.

1. Introduction

Marine litter is defined as any anthropogenic solid material that was incorrectly discarded or abandoned and found its way into coastal and marine environments, therefore including those transported through water streams and winds (Buhl-Mortensen and Buhl-Mortensen, 2017). This type of contaminant has been reported on coasts worldwide, also in bottom sediments, and surface ocean waters (Hengstmann et al., 2017;

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Miyazono et al., 2021; Renzi et al., 2019). In recent decades, plastic pollution has become a major environmental problem (Abelouah et al., 2023; De-la-Torre et al., 2023). This is reflected in marine litter, which is mainly composed of plastics (Ertaş et al., 2022; Ribeiro et al., 2021).

It is widely known that plastic threatens marine biota in multiple ways. For instance, some organisms ingest plastic of various sizes or become entanglement and/or entrapped in plastic litter by accident, which severely compromises their survival (Costa et al., 2022; Thiel et al., 2018a). These type of interactions has been reported in marine mammals (Poeta et al., 2017b), birds (Battisti et al., 2019b), and reptiles (Staffieri et al., 2019), among others, worldwide. In addition, plastic may serve as a substrate for the proliferation of invertebrates and other marine organisms (Cesarini et al., 2022; De-la-Torre et al., 2023); this interaction may contribute to the dispersal of alien invasive species since plastic can float for large distances (rafting) (Mghili et al., 2022; Póvoa et al., 2022; Rech et al., 2021). Apart from colonization, studies have reported the occurrence of fish eggs deposited on plastic, often called plastic rafts, raising concerns regarding the dispersal of vertebrate species (Cordeiro and Oddone, 2019; Subías-Baratau et al., 2022). However, reports on this issue are so far very scarce and the impact on oviparous species is poorly understood (De-la-Torre et al., 2022e; Shruti et al., 2023).

Skates (Order: Rajiformes) are cartilaginous fish widely distributed worldwide, living primarily on the seafloor. These species are oviparous, therefore laying egg capsules containing a single embryo (Chiquillo et al., 2014; García-Salinas et al., 2021). They are characterized by the production of relatively large eggs which, once fertilized, are encased and protected by a structurally complex and remarkably resistant leathery capsule made of reticulate proteins with antimicrobial and antifouling properties (Moya, 2017; Seguel et al., 2022). The capsules are released into the medium and the embryo completes its development inside the capsule, consuming the accumulated nutrients. The resulting hatchling emerges fully developed and appears to be a miniature adult (Moya, 2017). The eggs have an estimated hatching time of approximately 4 months (Zavalaga et al., 2021).

The Wira or Short-Tailed Fan Skate (*Sympterygia brevicaudata*) (Rajiformes: Arhynchobatidae) is typical of shallow waters distributed in the southeastern Pacific, along the coasts of Ecuador, Peru, and central Chile (McEachran, 1982), inhabiting depths of 8 to 100 m and possibly beyond, as it has been caught incidentally in deep sea hake and crustacean fisheries operating up to 500 m depth (Dulvy et al., 2019). The reproductive cycle of the *Sympterygia* species studied so far coincides with the seasonality of coastal environments with maximum egg-laying activity in spring and hatching in summer (Mabragaña et al., 2015). Despite having protective characteristics, egg cases are vulnerable to external factors in the marine environment. Wave action, pathogens, and predation due to their high nutritional value are the main cause of mortality in fish eggs (Lucifora and García, 2004) since elasmobranchs have no parental care.

In Peru, anthropogenic activities, such as fishing and marine pollution, are some of the most relevant threats to cartilaginous fishes (Marín et al., 2018). Species like the *S. brevicaudata* have been classified as "Near Threatened" with a decreasing population trend by the International Union for Conservation of Nature (IUCN) Red List (https://www.iucnredlist.org/). Some studies have briefly reported the occurrence of egg capsules attached to stranded marine litter (Cordeiro and Oddone, 2019; de Ramos et al., 2021), which evidenced a singular type of skate-marine litter interaction. However, this interaction and the impact of marine litter on skates is poorly investigated, despite being a severe environmental problem (De-la-Torre et al., 2022e). Aiming to elucidate the uncertainties aforementioned, the present study performed a series of surveys on the northern Peruvian coast focusing on marine litter-containing skate egg capsules. The collected litter was characterized, while also describing the morphological characteristics of the egg capsules in order to better understand skate-marine litter interactions.

2. Materials and methods

2.1. Study site and sampling strategy

La Libertad Region is located on the northern coast of Peru. Some of the main economic activities in the province of La Libertad are the agricultural production of various crops, such as avocado (*Persea americana*), asparagus (*Asparagus officinalis*), and sugar cane (*Saccharum officinarum*), and archaeological tourism (Guerrero Padilla, 2019; Zapata and Borrego, 2014). Other activities include artisanal fishing with sustainable ancestral fishing techniques, such as "Caballito de Totora" (Bocanegra García and Veneros Urbina, 2020), and small-scale fisheries and vessels (De Lucio Burga et al., 2013). Fishing-associated litter (e.g., fishing nets and ropes) is a common sighting on the beaches of La Libertad, as well as commercially available products (e.g., plastic bottles, cigarette butts, cans, among others) and COVID-19-related waste (De-la-Torre et al., 2022b). However, there is not a clear understanding of the current state of marine litter contamination on the northern coast of Peru.

Between February and April 2022, several consecutive marine litter surveys were carried out on three beaches from La Libertad: Huanchaco (8°04′41.0″S 79°07′13.5″W), Salaverry (8°13′03.4″S 78°58′59.1″W) and Puerto Morin (8°24′43.0″S 78°54′06.5″W) (Fig. 1). A total of 10 sampling campaigns (2, 4, and 4 samplings in Huanchaco, Puerto Morin, and Salaverry, respectively) were conducted, and 6, 5.5, and 4.8 km of coastline were covered for Huanchaco, Salaverry, and Puerto Morin, respectively. At each beach, marine litter was visually identified by walking along the strandline. The great majority of marine litter containing egg capsules consisted of multiple types of litter entangled together (e.g., ropes, fishing nets, bags, wood), which was refer to as "conglomerate". The location of each conglomerate was recorded, as well as the number of egg capsules and their morphometric characteristics (i.e., length and width), probable hatching state (i.e., opened or closed), and color (i.e., fresh [yellowish or brownish] or dried [black]).

2.2. Litter characterization

Marine litter conglomerates were carefully disentangled on site. Each of the individual marine litter items within the conglomerates was classified based on the United Nations Environmental Program (UNEP) marine litter monitoring guidelines (Cheshire et al., 2009) with modifications. Two categories were added (OT05 for personal protective equipment [PPE] and OT06 for food wrapping or packets) by considering the current scenario of the COVID-19 pandemic and the extended use and disposal of food wrappings in Peru. Subsamples of each conglomerate were stored in Ziploc bags until further analysis.

2.3. FTIR spectroscopy and XRD

Eleven plastic items were randomly selected from the marine litter conglomerates to have their polymeric composition determined by FTIR analysis. Each item is better described in Table S1. The analysis was conducted using an IR affinity-01 (Shimadzu, Japan) coupled to a universal attenuated total reflectance (ATR) apparatus (MIRable™, PIKE Technologies) in order to obtain the infrared spectra of each sample (De-la-Torre et al., 2022d). The spectra were recorded at wavelengths between 400 and 4000 cm^{-1} and a resolution of 4 cm^{-1}. Key absorption bands of each spectrum were manually analyzed to determine the most-probable polymer identity following the description by Jung et al. (2018) and Veerasingam et al. (2020).

To analyze the chemical composition and structure of a subset of plastics, four items (white bag, green knotted rope, black braided net, and blue face mask) were analyzed by ATR-FTIR spectroscopy and X-ray diffractometry (XRD). The ATR-FTIR analysis of the four additional samples was carried out in an FTIR, Nicolet™ iS20 Spectrometer in ATR mode. The measurements of all of the samples were conducted with a

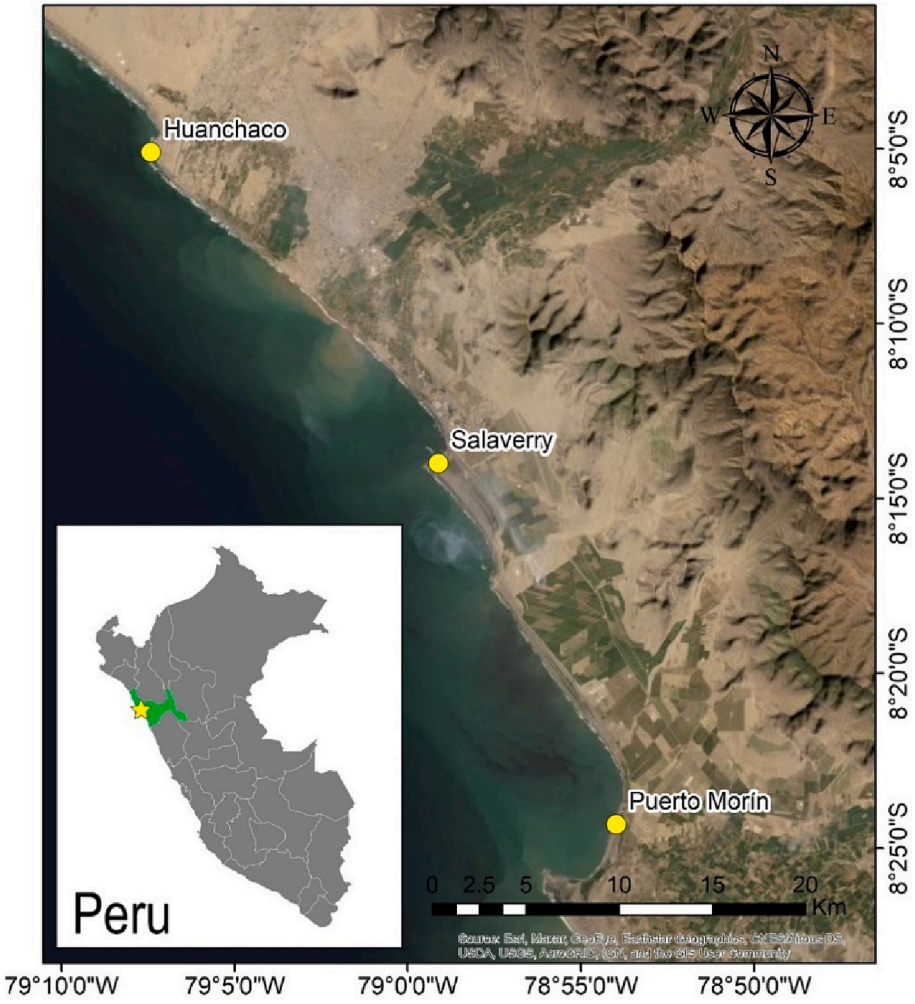


Fig. 1. Map of Peru emphasizing the northern coast. The three sampling locations are marked with a yellow dot. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

signal average of 124 co-added scans and a resolution of 4 cm^{-1}, recorded in the wave number range between 4000 and 600 cm^{-1}. XRD patterns of plastic litter samples were obtained using a PANalytical Empyrean 3 diffractometer with Ni-filtered Cu Kα radiation and a PIXcel3D detector following the methodology described by De-la-Torre et al. (2022b). The tested plastic samples were scanned from $2\theta = 10$ to 60° with a scanning rate of 0.2°/min.

3. Results

A total of 75 marine litter conglomerates were found containing a total of 1595 egg capsules (Fig. 2). Some examples are displayed in Fig. 3. Puerto Morin was the site where the majority of the conglomerates (62.6 %) and egg capsules (78.0 %) were found, followed by Salaverry (34.7 % and 18.5 % conglomerates and egg capsules, respectively) and Huanchaco (n = 2 and 54 conglomerates and egg capsules, respectively). Considering all sites, 84.2 % of the found egg capsules were dried and 15.8 % were fresh. Fresh egg capsules were only found in Puerto Morin (20.3 %), while 100 % of the egg capsules were dried in Salaverry and Huanchaco. Opened egg capsules represented 15.9 % of the total, and the rest were closed. Specifically, in Huanchaco, Puerto Morin, and Salaverry, opened egg capsules represented 50.0, 12.2, and 25.0 %, respectively (Table 1).

The mean length of the egg capsules was 43 ± 5.54 mm, and the width of the egg capsules was 29 ± 3.86 mm. The total mean length ranges varied between 27 and 58 mm and the mean width fluctuated between 19 and 48 mm. All measurements from Huanchaco, Salaverry, and Puerto Morin are summarized in Figs. S1–6.

February was the month with the most egg capsules found in the samplings. The mean total length and total mean width of egg capsules for this month were 44 ± 5.46 mm and 30 ± 3.73 mm, respectively. The total mean length varied between 29 and 58 mm and the mean width fluctuated between 20 and 48 mm. In April, egg capsules were only found in Puerto Morin, all the measurements for February, March, and April are summarized in Table 2.

Overall, the 75 conglomerates were composed of 316 individual marine litter of different types, primarily composed of plastic (65.2 %) and cloth (25.0 %), followed by rubber (4.7 %), and foamed plastic, metal, wood, paper & cardboard and other (up to 1.3 % each) (Fig. 3a). The composition of litter conglomerates in each sampling site is displayed in Fig. 3b–d, indicating that marine litter item types were more diversified in Salaverry, followed by Puerto Morin, and Huanchaco. Overall, plastic items were primarily composed of monofilament lines (20.4 %; PL18), followed by mesh bags (15.5 %; PL15), and plastic bags (12.6 %; PL07). Of the cloth items, 30.4 % were identified as clothing (CL01) and 22.8 % as ropes (CL04). Of the rubber items, 60 % was comprised of tires (RB04). The other items were composed of sanitary waste (50.0 %; OT02), face masks (16.7 %; OT05), electronics (16.7 %; OT03), and wrappings (16.7 %; OT06).

Four polymers were identified among the 15 plastic items sampled, based on their key absorption bands: polypropylene (PP – n = 4), low-density and high-density polyethylene (LDPE – n = 3; HDPE – n = 1),

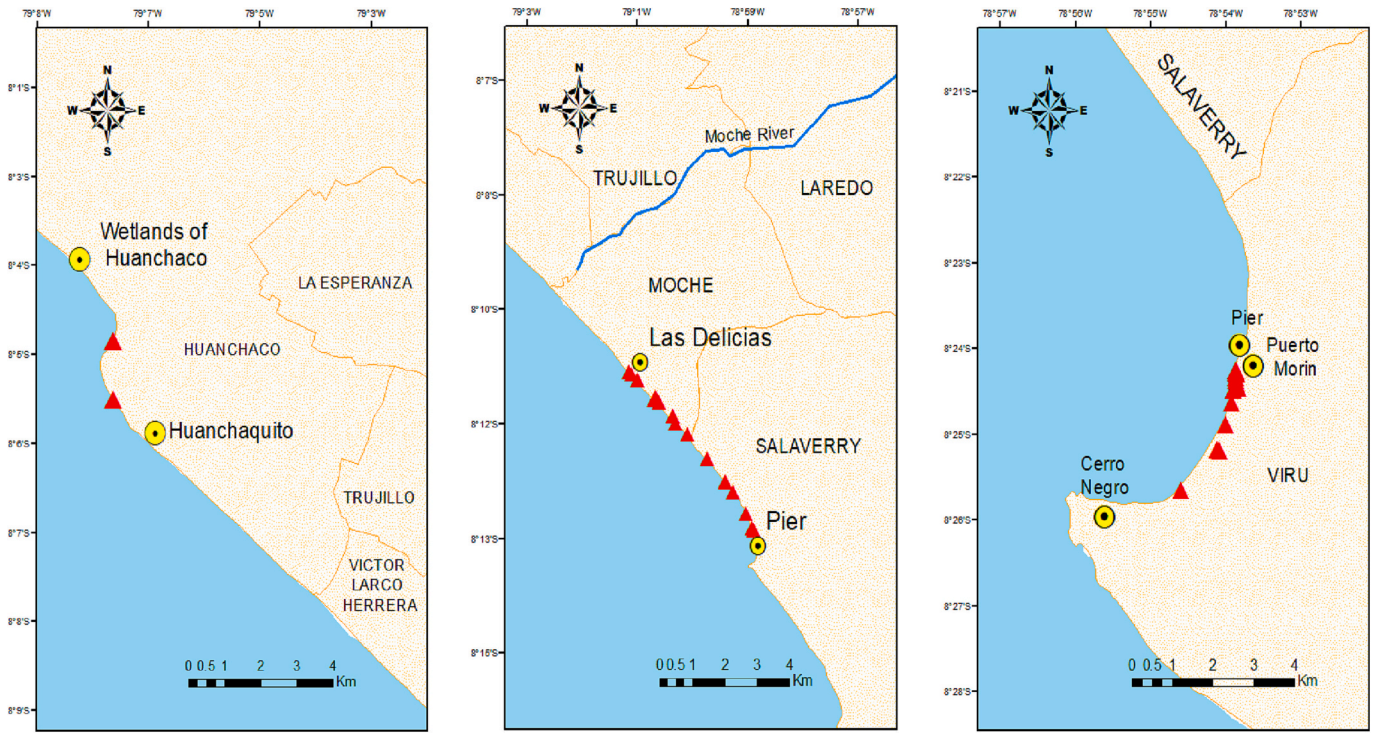


Fig. 2. Location of marine litter conglomerates across the three localities: Huanchaco (left), Salaverry (center), and Puerto Morín (right). Red triangles indicate the location of individual marine litter conglomerates found. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

polyethylene terephthalate (PET – n = 3), and nylon (n = 4). Examples of analyzed samples and their respective FTIR spectra are shown in Fig. 4. The full description and identified polymer composition of each sample are displayed in Table S2. The identification was carried out according to Jung et al. (2018) and Veerasingam et al. (2020), and the associated of selected absorption bands to the vibration of specific functional groups are displayed in Table S3. Additionally, signs of chemical degradation were observed. In brief, PP and LDPE samples showed additional bands, including a broad peak at around 3400 cm^{-1}, and a sharper peak at around 1640 cm^{-1}, which are generally associated with hydroxyl and carboxyl groups, respectively (De-la-Torre et al., 2022a).

According to the XRD patterns of the plastic litter, all the samples analyzed exhibited diffraction peaks attributed to their semi-crystalline structure. The XRD pattern of the HPDE white bag sample showed strong diffraction peaks appearing at around 2θ = 21.61°and 2θ = 23.9° associated with (110) and (200) lattice planes. Whereas moderate peaks at 2θ = 30.35 and 2θ = 36.2 also were observed, which correspond to the (210) and (020) lattice planes, respectively (Fig. 5a). The FTIR spectra showed strong stretching vibration in the regions at 2919 cm^{-1} and 2850 cm^{-1} associated with CH_2 asymmetric and symmetric C—H stretch, respectively (Veerasingam et al., 2020). The peak in the region 1472 cm^{-1} is associated with asymmetric deformation vibrations of C—H (phase crystalline phase). The sharp band occurring at around 720 cm^{-1} is associated with CH_2 rocking vibrations (Benabid et al., 2019). It is important to mention that the CH_2 rocking peak in HDPE is split because the CH_2 chains can orient parallel to each other forming long-range ordered crystalline areas. When CH_2 groups absorb photons of the appropriate energy simultaneously, they can vibrate in-phase and out-of-phase with each other, generating a split CH_2 rocking peak at 720 ± 10 cm^{-1} (Veerasingam et al., 2020). Moreover, the small inserted photograph of the white bag showed that the sample exhibited fractures, cracks, and fellowship areas. The PP green knotted rope exhibited a strong peak centered at 2θ = 13.90° and moderate peaks at 2θ = 18.4°, and 2θ = 25.4°, corresponding to the α-form crystallographic planes (110), (040), (130), and (060), respectively (Wang et al., 2017). The peak at 2θ = 21.5° corresponds to (111/041) lattice planes which is also the characteristic of the α-form PP (De-la-Torre et al., 2022b) (Fig. 5b). The FTIR spectra showed absorption bands typically related to the PP structure aforementioned. A photograph of the sample showed particulate matter adhering to their surface and microfibers sticking out of the string pattern. In the case of the PA black braided net, the 2θ ranges of the diffraction peaks from the XRD pattern (Fig. 5c) are consistent with the Nylon pattern, exhibiting the characteristic peaks at 2θ ≈ 20.15° and 23.6° and indicating the presence of ∝ − phase in the polymeric structure (Forero-López et al., 2022). FTIR spectra displayed typical bands of functional groups of this thermoplastic. The absorption band at 3296 is attributable to the hydrogen-bonded N—H stretching vibration, whereas the bands at 1645 and 1534 cm^{-1} are related to the N—H amide I, C═O stretching vibration and amide II, C—N stretching, and CO–N–H bending vibration of the amide bond, respectively (Forero-López et al., 2022; Rwei et al., 2019). The band at 1262 cm^{-1} is associated with amide IV, C–CO stretching vibration (Rwei et al., 2019). In particular, the FTIR spectra present typical polymeric signals of Nylon, there is a strong peak at 1030 cm^{-1}, which is attributed to inorganic mineral residues such as PO_4^{3-}, NO^{3-} or Si—O (Forero-López et al., 2022). A photograph of the black net sample showed minerals particles adhered to their surface, which were confirmed through XRD pattern analysis. Finally, the blue face mask sample found in the litter entangled is made with Nylon 6,6, however, the intensity of signals in some functional groups from the FTIR spectra is less than a black braided net. Likewise, some changes in the intensity and the shape diffraction peaks in the XRD pattern of the face mask were less sharp and less intense that nylon 6,6 pattern (Forero-López et al., 2022), indicating some weathering degree of the sample (Liu et al., 2020) (Fig. 6).

4. Discussions

As expected, the majority of marine litter items found composing the conglomerates were plastics (65.1 %), which is in accordance with

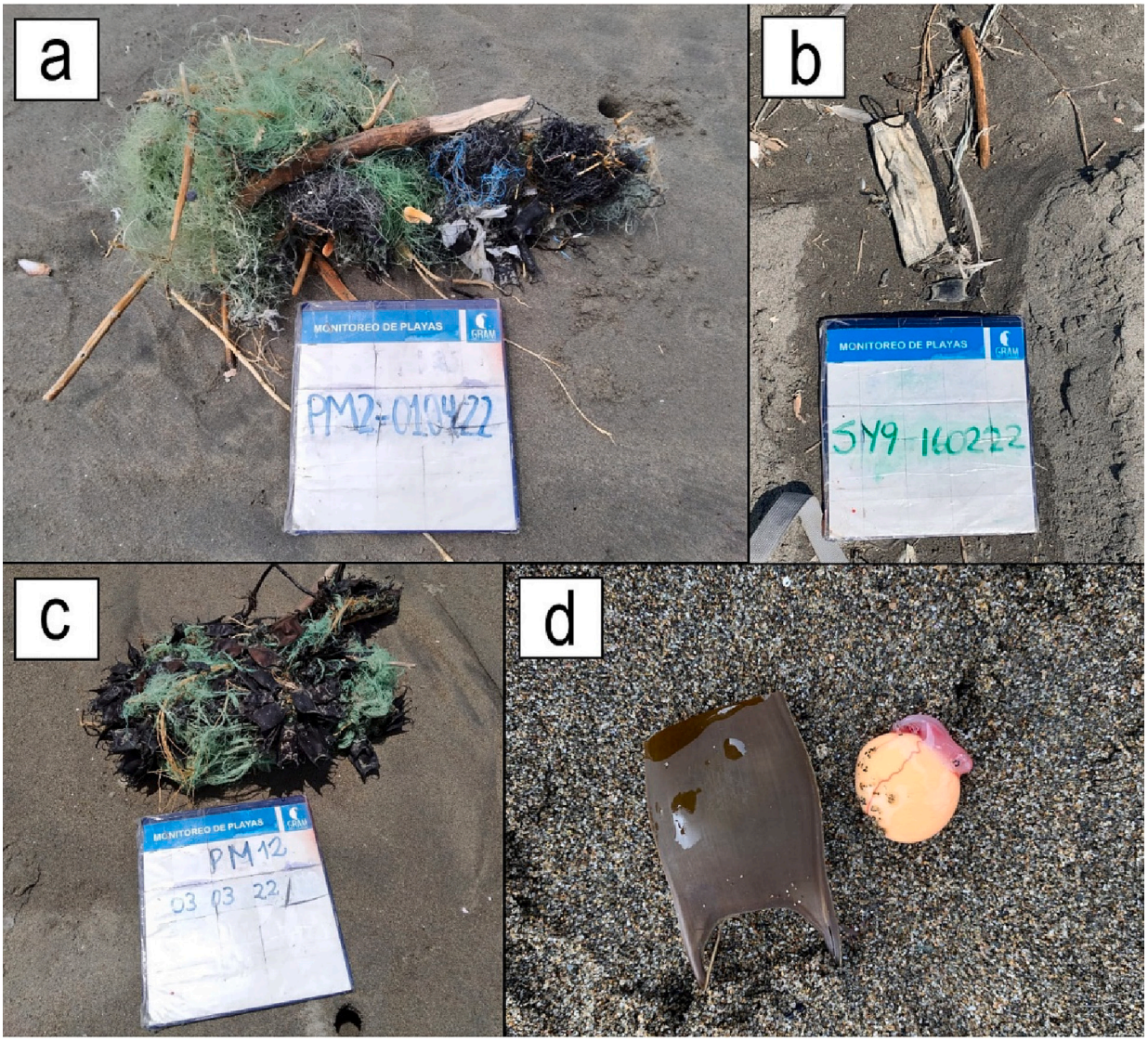


Fig. 3. Field photographs of a) a conglomerate consisting of multiple marine litter types (e.g., fishing net, unprocessed timber, monofilament lines, threads, etc.) b) a surgical face mask with an egg capsule attached, c) a conglomerate consisting of primarily fishing nets, and d) a *Sympterygia* sp. embryo with its yolk sac extracted from a stranded fresh egg capsule.

Table 1
Mean values and ranges of measurements of egg capsules from Huanchaco, Salaverry y Puerto Morin.

	Number of egg capsule	Egg capsule length (mean ± SD)	Egg capsule width (mean ± SD)	Range egg capsule length (mm)	Range egg capsule width (mm)
Total	1835	43 ± 5.54	29 ± 3.86	27–58	19–48
Huanchaco	54	48 ± 3.25	32 ± 2.01	40–54	24–36
Salaverry	296	43 ± 5.3	3 ± 3.98	29–58	20–48
Puerto Morin	2507	43 ± 5.58	29 ± 3.82	27–58	19–41

Table 2
Mean values and measurement ranges of egg capsules from February, March and April of the 3 sampled sites.

	Number of egg capsules	Egg capsule length (mean ± SD)	Egg capsule width (mean ± SD)	Range egg capsule length (mm)	Range egg capsule width (mm)
Total	1835	43 ± 5.54	29 ± 3.86	27–58	19–48
February	881	44 ± 5.46	30 ± 3.73	29–58	20–48
March	861	42 ± 5.64	28 ± 3.75	27–58	19–41
April	93	44 ± 2.43	30 ± 1.64	36–49	24–33

previous worldwide marine litter surveys (Chassignet et al., 2021; Löhr et al., 2017). For instance, in the Santos Estuarine System, plastic items ranged from 64.8 to 72.5 % depending on seasonality (Ribeiro et al., 2021), while in other regions exceeded 90 % (Pieper et al., 2019). It should be noted that in most cases, the UNEP category "foamed plastic" is considered within a "plastics" category. This is because most commercially available foams, such as insulators and food packaging, consist of expanded polystyrene. Polystyrene waste materials have been reported as suitable substrated for the proliferation of plants (Battisti et al., 2020; Poeta et al., 2017a) and other species (De-la-Torre et al., 2023). On the other hand, most textiles and cloth items are composed of synthetic polymers, such as polyester, acrylic, rayon, and PA (De Falco et al., 2019; Periyasamy and Tehrani-Bagha, 2022). In the present study, the majority of the plastic items were composed of monofilament lines

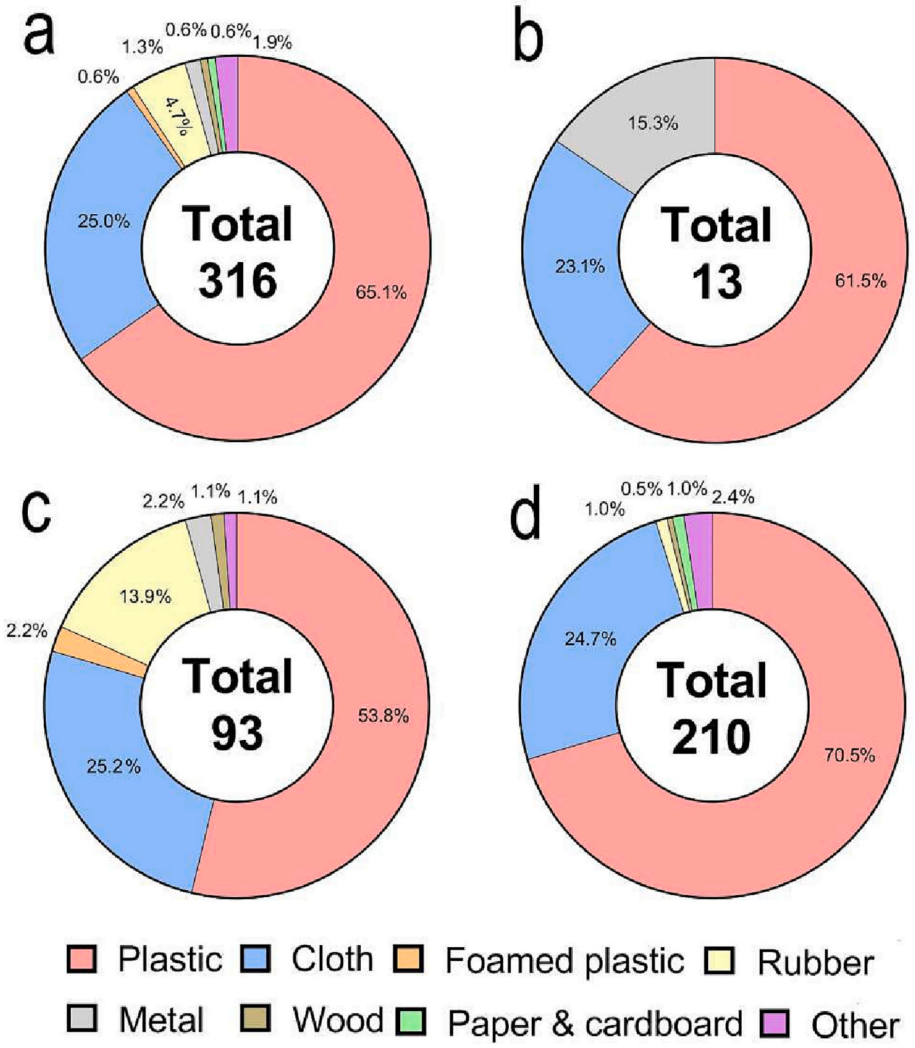


Fig. 4. Pie charts displaying the proportion of different types of litter overall (a), at Huanchaco (b), Salaverry (c), and Puerto Morin (d).

(20.4 %) and 22.8 % of the cloths were ropes, suggesting that fishing-derived activities are a significant contributor to this issue. It has been estimated that artisanal fishing vessels in Peru generate about 0.045 kg of fishing nets and 0.008 kg of plastic waste per crew member per day (Ortiz-Alvarez et al., 2022). While it is well known that many artisanal fishermen opt for tossing their solid waste down the board, to the best of our knowledge, there are no detailed studies on solid waste management strategies and fishermen's behavior on board. Interestingly, the contribution of fishing gear to the overall amount of marine litter reported in the marine and coastal environment is relatively low (Gilman et al., 2022; Krelling et al., 2023), although they have been reported entrapping marine macroalgae (Battisti et al., 2019a).

Interestingly, several face masks were found entangled within the marine litter conglomerates and one even had an egg capsule attached to it (see Fig. 3d). The number of face masks accounts for a small percentage of the total marine litter items, however, the environmental side-effects of the COVID-19 measures to prevent the transmission of the virus (e.g., wearing face masks) can be observed. It has been estimated that face mask waste generation in La Libertad Region reached almost 1 million face masks per day during the peak of the pandemic (Torres and De-la-Torre, 2021). Evidently, PPE pollution has been reported on beaches along the Peruvian coast and in nature-protected areas (De-la-Torre et al., 2022b, 2021b; Dioses-Salinas et al., 2022). Thus, it is no surprise that face masks were found incorporating marine litter conglomerates, which elucidates the complex traces of environmental contamination driven by the pandemic.

It is known that discarded fishing gear can have a negative effect on benthic species, through ghost fishing. In the northern region of Peru, Ganoza Chozo et al. (2014) showed that fishing gear can continue catching multiple species while they remain in the ocean while being dragged by marine currents. Considering that only a few egg capsules (attached to their natural substrata or alone) are observed washed on the strandline per sampling procedure, it is safe to assume that marine litter, mainly composed of fishing-related items, are a key driver of these types of events. Thus, our results demonstrated that fishing litter could have a significant impact on the population of *Sympterygia* sp., although more studies are required to quantify it. Marine litter conglomerates with the presence of *Sympterygia* sp. egg capsules were more abundant in Puerto de Morin, possibly related to oceanographic conditions in this region. It should be taken into account that the movement and accumulation of fishing gear are related to the marine circulation triggered by the combination of winds, tides, and density differences (Macfadyen et al., 2009). In particular, the zone off Puerto Morin is characterized by a closed circulation, possibly due to the projection of the coast towards the ocean at its southern limit (La Punta Cerro Negro). For this reason, the general circulation of the region is not followed at Puerto Morin. The Puerto Morin zone presents surface and subsurface currents with cyclonic movement, with a greater resident time of their waters and a greater probability of transporting these conglomerates towards the coast, unlike Huanchaco and Salaverry, where the currents flow from

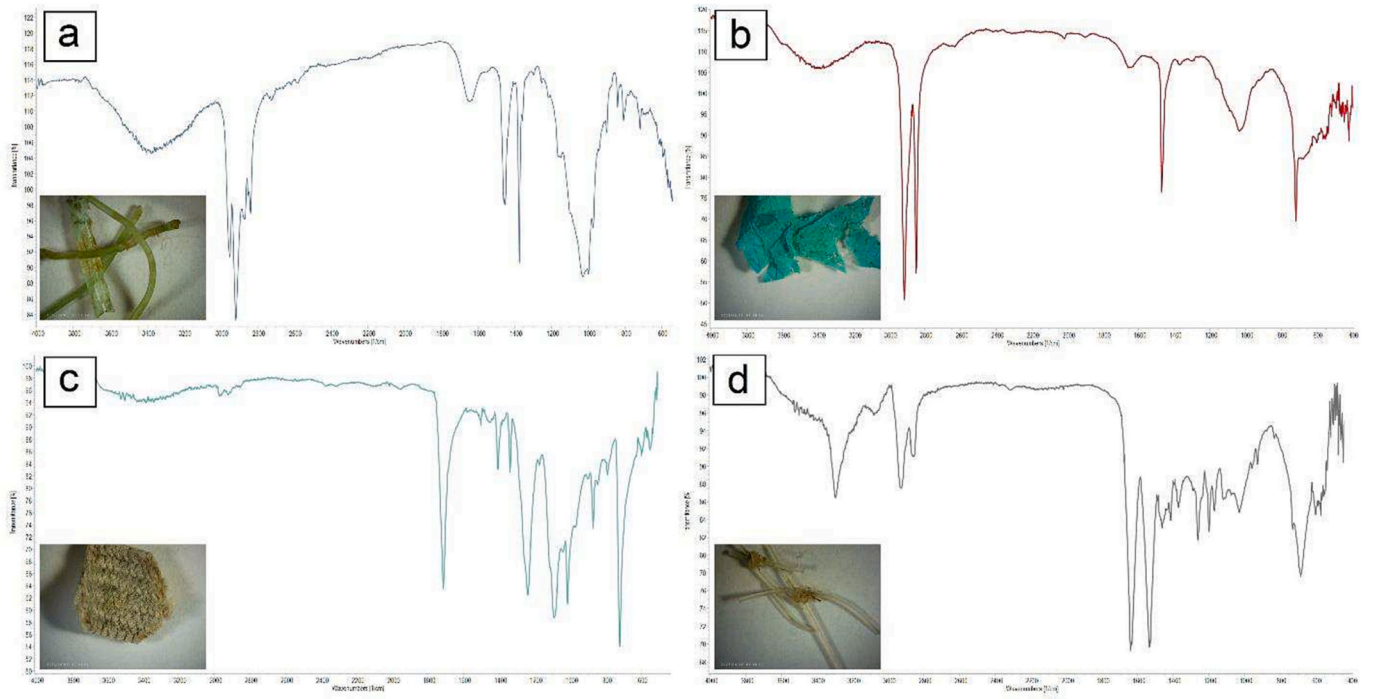


Fig. 5. FTIR spectra of a green monofilament line identified as PP (a), blue plastic film identified as LDPE (b), face mask earloop identified as PET (c), and white knotted monofilament line identified as Nylon (d). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

south to the northwest (De Lucio Burga et al., 2013; Rebaza Castillo and Alfaro Mudarra, 2019) being able to renew its waters more frequently.

Polymer identification allowed us to preliminarily comprehend the chemical composition of different marine litter item types, as well as their possible sources. For instance, blue and white plastic films were confirmed as LDPE by FTIR, suggesting that they were derived from single-use plastic bags. A transparent rigid plastic sheet was identified as PET, which is most likely a piece of a plastic bottle. Interestingly, the earloop piece of an entangled face mask was identified as PET as well, and a sample of red plastic strips was identified as PP, although their original source is unknown. Regarding fishing gear, different types of fishing nets (e.g., braided, twisted, and monofilament nets) and ropes were identified as PP, Nylon, LDPE, and PET. This puts into perspective the variety of synthetic polymers used in fishing activities.

Coastal plastic surveys and characterization in Peru indicated the presence of similar polymeric compositions. An investigation on the colonization of stranded marine litter in Lima, Peru, showed that the colonized substrates were composed of PP (mostly mesh bags and fishing nets), LDPE (single-use plastic bags), polyester (textiles and fabrics), PA (textiles and fishing nets), and Latex (plastic soft sheeting) (De-la-Torre et al., 2021a), while PPE surveys indicated that face masks were mainly composed of PP or cotton-polyester layers (for surgical and reusable face masks, respectively) with PA or PET earloops (De-la-Torre et al., 2022b; Dioses-Salinas et al., 2022). Other types of novel plastic forms, such as plastiglomerates and pyroplastics, found in the central and northern coast of Peru were mainly composed of PP, HDPE, PA, and PET (De-la-Torre et al., 2022d). The majority of synthetic polymers found in marine litter surveys agree with the present study, suggesting that litter typology and composition follow similar patterns at close geographical locations, like the central and northern coasts of Peru.

Apart from the evident impact generated by marine litter at the earliest stages of the development of *Sympterygia*, the release of secondary contaminants should be taken into account. Upon release, plastics are subject to several environmental stressors, such as UV light exposure, interaction with biota, and wave action. The molecular changes that synthetic polymers undergo after being exposed to UV light (e.g., chain scission and photo-oxidation) result in the embrittlement of the material (Pizarro-Ortega et al., 2022), which is then easily fragmented into smaller plastic debris under mechanical stressors (Andrady, 2022; Andrady et al., 2022). Small plastic debris, such as microplastics (MPs; between 1 μm and 5 mm in size) and nanoplastics (NPs; <1 μm in size), are some of the most concerning environmental contaminants in the last decade (Sorensen and Jovanović, 2021) due to their widespread distribution, interaction with external contaminants, and toxicity (Benson et al., 2022; Kroon et al., 2020; Torres et al., 2021). MPs have been found in all environmental compartments and ingested organisms from all taxa (Ben-Haddad et al., 2022; Saldaña-Serrano et al., 2022; Truchet et al., 2021; Villagran et al., 2020). In Peru, the presence of MPs on beaches from the central coast was primarily attributed to PS-based food packaging and fishing activities (e.g., PP lines and fibers) (De-la-Torre et al., 2020). On the other hand, polyester, PE, PP, and PS MPs have been found contaminating market bivalves meant for human consumption from different Peruvian provinces, attributed to environmental pollution and handling (including the use of PP-based fishing gear) (De-la-Torre et al., 2022c). Although there are various reports of plastic and MP pollution in Peru, the majority lack a crucial step which is the identification of the polymer composition through spectroscopic techniques. The inaccessibility to advanced equipment poses a barrier to conducting comprehensive plastic pollution studies, compromising the identification of plastic sources and confirmation of suspected plastic debris. In the present study, polymer identification was conducted preliminarily. However, it necessary that future studies make greater efforts to analyze at least 50 % of all the items found, as well as combining other materials science techniques (e.g., X-ray crystallography, scanning electron microscopy, energy dispersive X-ray spectroscopy, and thermal gravimetry, among others) to elucidate the various aspects of interest in the field of plastic pollution, such as physical and chemical degradation, presence and release of chemical additives and contaminants, stability and sources of contamination.

Despite the widespread distribution and abundance of marine litter worldwide, the reports of similar observations are very few. For instance, de Ramos et al. (2021) found *Sympterygia* egg capsules

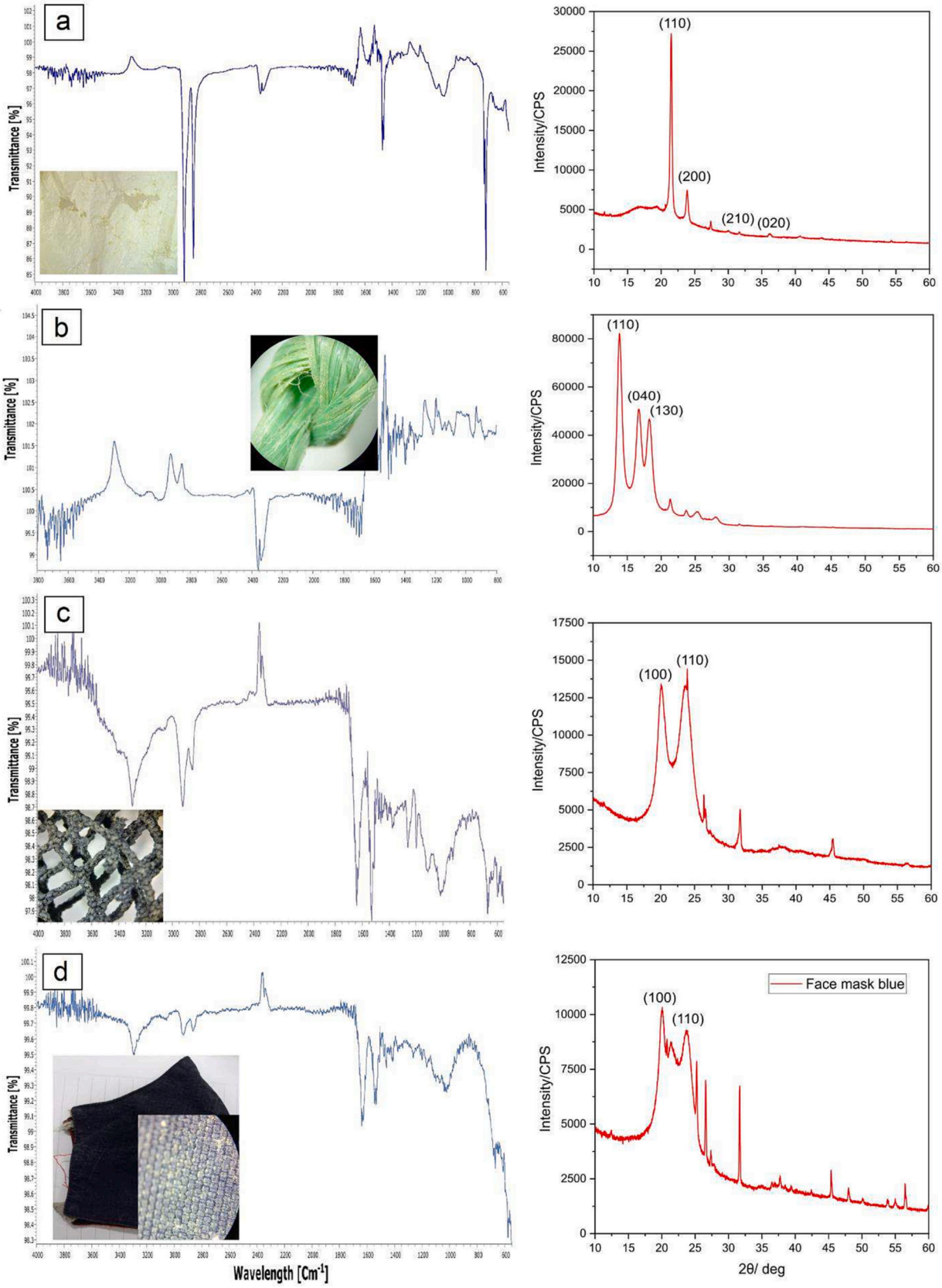


Fig. 6. Photographs of a a) HDPE white plastic bag, b) PP green knotted rope, c) PA black braided net, and d) and PA blue face mask with their respective FTIR spectra and XRD patterns. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

entangled in fishing nets during a marine litter characterization study at Cassino beach, Brazil. Similarly, Cordeiro and Oddone (2019) investigated the diversity and abundance of skate egg capsules along Cassino beach. In the case of *Sympterygia acuta*, several egg capsules were found attached to marine litter items, such as plastic bags, fishing nets, and ropes. The same group published a similar report more than a decade before (Oddone and Vooren, 2002). Personal observations by Thiel et al. indicated that *Sympterygia* egg capsules are commonly found attached to plastic litter floating near the central coast of Chile or stranded after storm events (Thiel et al., 2018b). Regardless, none of the previous studies focused on investigating whether using marine litter conglomerates as nesting grounds could affect *Sympterygia* communities. Not much attention is given to the occurrence of egg capsules in marine litter, which are displayed as interesting findings. In the case of other cartilaginous fish species, egg capsules of the catshark (*Scyliorhinus* sp.) were found attached to benthic plastic debris in the Catalan sea (Subías-Baratau et al., 2022). The authors highlighted the possible implications of this finding on the dispersal and habitat distribution of this species of catshark. Considering the scarcity of field data on the interaction and stranding of egg capsules attached to marine litter, researchers must carry out surveys focusing on this type of findings, as well as combining meteorological events and marine litter sources as the main drivers of egg capsule strandings.

Capsules constitute the outermost covering of the egg of cartilaginous fish, which protects the embryo during its development (Concha et al., 2013). The external morphology of each capsule is particular to each species, so it is used as a taxonomic tool in species identification (Treloar et al., 2006). The cases are released into the marine environment and the embryo completes its development inside the case, consuming the accumulated nutrients. The resulting hatchling emerges fully developed in approximately 4 months and shares the same morphological characteristics as an adult (there is no larval phase in elasmobranchs) (Moya, 2017; Zavalaga et al., 2021). On a chemical level, egg cases are a combination of collagen and polyphenols, which gives them specific filtering properties resistance (Ehrlich, 2015), hardness, and flexibility; capsular fluids have an ionic composition almost identical to that of seawater, which allows them to be permeable (Knight et al., 1996).

Unlike the eggs of other batoids, the egg cases of *Sympterygia* have extremely long elongated structures called "tendrils" (Seguel et al., 2022), a characteristic that is not common in rays and seems to occur only within the genus *Sympterygia*, thus, becoming a useful characteristic to distinguish them from other egg cases in the same latitudinal range (Concha et al., 2013; Seguel et al., 2022). The tendrils allow females to entwine them firmly in structures such as brown algae or other available substrates, unlike other batoid species that lay their egg cases on the seafloor (Seguel et al., 2022). Likewise, the cases of this genus have a pale yellow-brown coloration, which with time turns to a dark brown (Concha et al., 2013).

Regarding *Sympterygia* females deposit their eggs, observations were made in a female of *Sympterygia lima* in captivity (Concha et al., 2013). It was recorded that the long-coiled tendrils are the first to emerge through the cloaca during egg laying, and the female searched for a substrate to attach to. After attaching the tendrils to the substrate, the female rested for less than a minute and then swam away from the tendril attachment point to expel the egg cases. Following the first clutch, the second pair of tendrils, belonging to the second capsule, emerges from the cloaca. The development of extremely long horns, which help ensure anchorage with the substrate, could have important biological implications because the upright position of the egg cases is thought to encourage passive oxygen flow (Concha et al., 2013) (Fig. 7).

The characteristics of large fishing gear litter, such as being able to be anchored momentarily to the sea bed and being lightweight enough to have some movement similar to that of algae, make them a potential alternative substrate for the skate to lay their eggs. We suspect that marine litter conglomerates reaching bottom sediments may serve as a substrate for oviposition and later detach or lose weight under unknown conditions, resulting in their stranding (Fig. 8).

5. Conclusions

The present study investigated an overlooked pathway by which

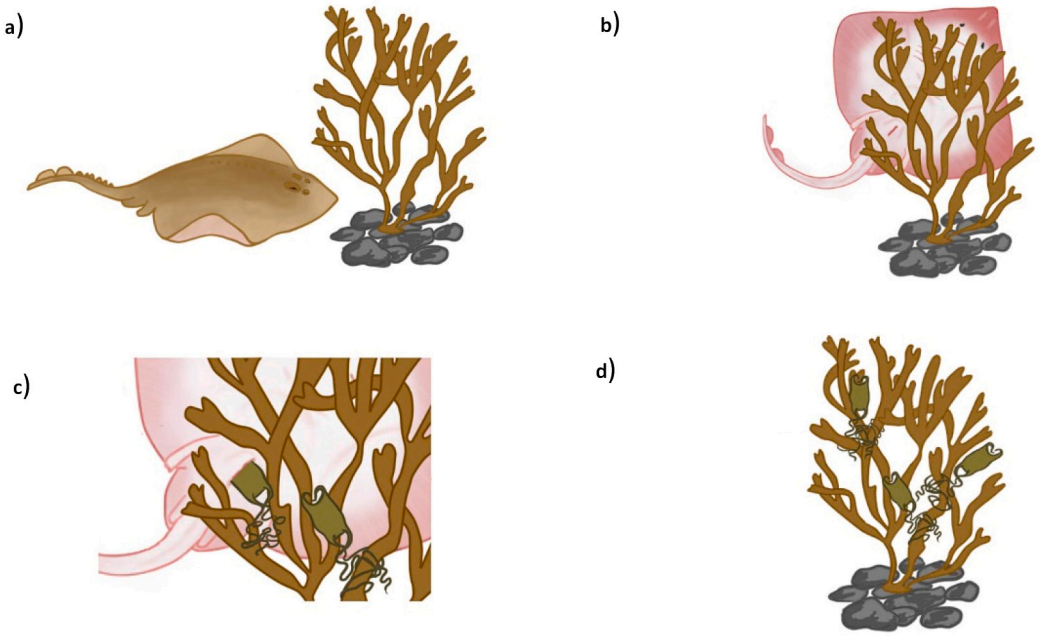


Fig. 7. Normal *Sympterygia* spawning: The female approaches a substrate to lay the eggs, in this case, a brown alga (a), places the cloaca near the fronds (b), egg capsules emerge from the cloaca with the tendrils in position to attach them to the stipe or the blade of the alga (c). The female can rub its belly to the substrate in order to entangle the cases, once the eggs are anchored, the females leave them in the substrate (d).
Illustration by Armando Isla-Ventura.

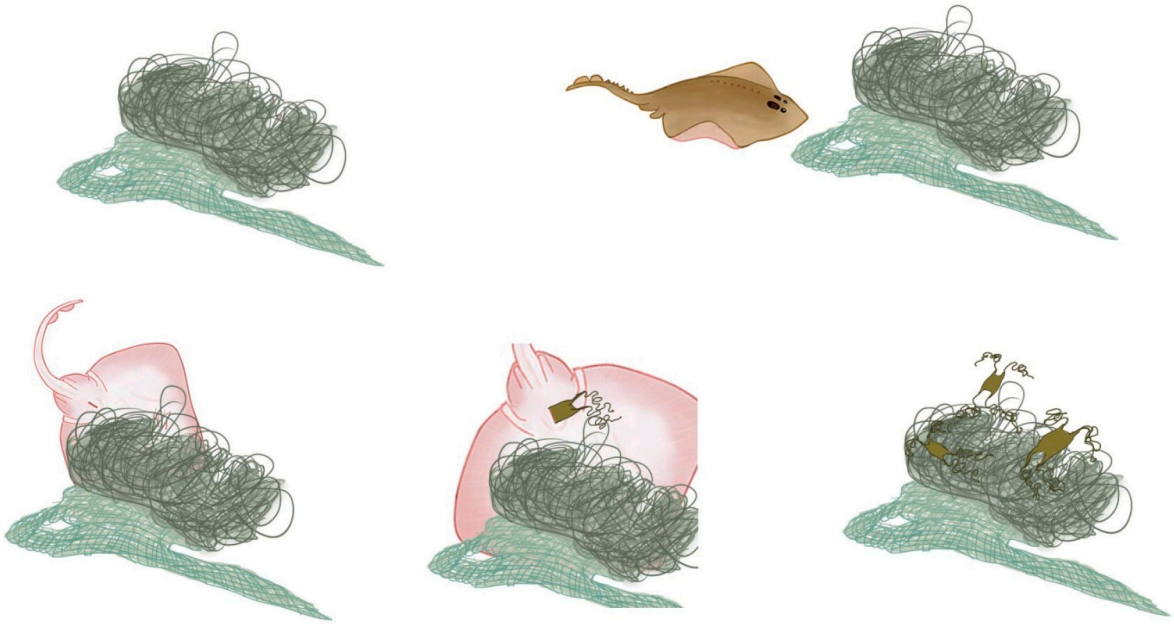


Fig. 8. *Sympterygia* spawning in marine debris: The female approaches a substrate to lay the eggs, in this case, fishing gear: As if it were algae, the female will rub its belly while ejecting the egg cases and they will be entangled to the net.
Illustration by Armando Isla-Ventura.

marine litter is impacting skate communities in northern Peru by driving a large-scale stranding of viable and unhatched egg capsules. We suggest that *Sympterygia* skates choose marine litter as a suitable nesting ground by mistake, which is later washed ashore with unhatched eggs. In only 10 sampling campaigns, we found 75 marine litter conglomerates with >1500 egg capsules, out of which the great majority were closed (presumably unhatched). The impact of this phenomenon on the *Sympterygia* communities of northern Peru is poorly understood due to the insufficient data available. Regardless, we believe that the loss of thousands of individuals during the prenatal state is an alarming indicator of the impacts of marine litter pollution and uncontrolled waste management and disposal onboard.

CRediT authorship contribution statement

Miguel Valderrama-Herrera: Conceptualization, Methodology, Investigation, Resources, Writing – review & editing, Supervision. **Sara Amada Cardenas:** Formal analysis, Investigation, Writing – review & editing. **Carlos Calvo-Mac:** Conceptualization, Methodology, Resources, Funding acquisition. **Renzo Gustavo Celi-Vértiz:** Investigation, Resources. **Valeria Liz Chumpitaz-Levano:** Investigation, Resources. **Walter Eduardo Flores-Miranda:** Investigation, Resources. **Zoila M.T. Lopez-Tirado:** Investigation, Resources. **Mariana Molina-Alvarez:** Investigation, Resources. **Diana N. Rubio-Cheon:** Investigation, Resources. **Maryalejandra Trucios-Castro:** Investigation, Resources. **Melisa D. Fernández Severini:** Methodology, Software, Resources, Writing – review & editing. **Ana D. Forero López:** Methodology, Software, Resources, Writing – review & editing. **Williams Ramos:** Methodology, Software, Resources, Writing – review & editing. **Victor Pretell:** Methodology, Software, Resources, Writing – review & editing. **Italo B. Castro:** Investigation, Writing – review & editing. **Victor Vasques Ribeiro:** Investigation, Writing – review & editing. **Sina Dobaradaran:** Investigation, Writing – review & editing. **Dante Espinoza-Morriberón:** Validation, Investigation, Writing – review & editing. **Mohamed Ben-Haddad:** Investigation, Writing – review & editing. **Diana Carolina Dioses-Salinas:** Investigation, Writing – review & editing. **Gabriel Enrique De-la-Torre:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Project administration, 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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2023.114941.

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