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ORIGINAL PAPER

Presence of microplastic in target species of small scale fisheries and possible social implications on the local communities

Omar Rivera-Garibay[1,2,3] · María Elena Méndez-López[4] · Edgar Torres-Irineo[5] · Miguel Rivas[6] · David Santillo[7] · Lorenzo Álvarez-Filip[1]

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Abstract

Microplastic ingestion by marine fishes has been of particular interest, as many species are the target of commercial fisheries and, thus, have a strong connection with human health. Consumption of microplastic thru seafood is likely to have harmful effects on people globally but mainly on social groups that highly depend on fisheries for self-consumption. Here, we first aim to characterize the presence of microplastics in species targeted by small-scale fishers; and explore if the fish consumption of microplastic particles is associated with biological factors. Second, we applied semi-structured interviews to small-scale fishers to investigate, from a socio-environmental perspective, the potential social and environmental impacts of contamination by microplastics on the local communities. We found that commercially important fish families regularly contained microplastics in their tissues, and the consumption of microplastics by fish caught through traditional fishing gear depends on traits such as species mobility but the microplastic load also depended on the type of fishing gear used. Species with a wide home range had a higher load of microplastics than fish with a small home range but also seemed to be related to the fishing method. The observed differences in microplastic content on target species are likely to be transferred to humans in a non-random fashion. This work implies that microplastic pollution in commercial fish might represent an environmental and social issue that is not well understood by the fishing community in the Mexican Caribbean, with potential ramifications for marine resource management.

Keywords Microplastics · Commercial fish · Social implications · Mexican Caribbean · Small scale fisheries

Introduction

Plastics are a major contaminant in the world's oceans because it takes a long time scales for them to degrade naturally (Law et al. 2010; Mendenhall 2018). It has been estimated that, since 1950, 196 million tons of plastics have entered the ocean (Koelmans et al. 2017) and according to Babaremu et al. (2022) the global production of plastic in 2021 is projected to be around 400 million tons to 414 million metric tons disregarding the impact of COVID-19. Large plastics continuously degrade to small-sized plastics and are the precursor of microplastics (< 5 mm) (Kühn and van Franeker 2020; Mendenhall 2018), conversely, small plastics intentionally crafted for specific industrial

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Omar Rivera-Garibay
orivera@cobi.org.mx

Lorenzo Álvarez-Filip
lorenzo@cmarl.unam.mx

[1] Biodiversity and Reef Conservation Laboratory, Unidad Académica de Sistemas Arrecifales, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Puerto Morelos, México

[2] Posgrado en Ciencias de la Sostenibilidad, Universidad Nacional Autónoma de México, Ciudad de México, México

[3] Comunidad y Biodiversidad, A.C., Isla del Peruano 215, Guaymas, 85448 Sonora, Mexico

[4] Consejo Nacional de Ciencia y Tecnología, Centro de Investigación en Ciencias de Información Geoespacial, Mérida, México

[5] Escuela Nacional de Estudios Superiores Unidad Mérida, Universidad Nacional Autónoma de México, Mérida, México

[6] Oceana, Ciudad de Mexico, México

[7] Greenpeace Research Laboratories, University of Exeter, Exeter, UK

purposes infiltrate the marine ecosystem via a multitude of terrestrial and aquatic pathways (Auta et al. 2017). Due to the enduring nature and buoyancy of microplastics, they have the capacity of to travel long distances before they settle into sediments (Mendenhall 2018). Therefore, microplastics are widely distributed in every sub-zone/layer (pelagic and benthic) of coastal and marine systems (Jiang and Li 2020; Thushari and Senevirathna 2020) and are essentially found in all investigated species regardless of their habitat preference or trophic level (Hale et al. 2020; Savoca et al. 2021). The incidence of plastic ingestion in marine fish has been annually growing by > 2% since 2010 (Savoca et al. 2021). Therefore, microplastics have become an increasingly concerning problem as they may pose a potential health risk for marine organisms and humankind (Barboza et al. 2018; Zhang et al. 2021).

Microplastic ingestion by marine fishes has been of particular interest, as many species are the target of commercial fisheries and, thus, have a strong connection with human health (Walkinshaw et al. 2020). Fish might intentionally consume microplastics, often due to confusing these particles with natural prey like plankton, or unintentionally if the microplastics were already attached to or inside the prey (Jovanović 2017; Markic et al. 2020). This ingestion in some species can generate the physical blockage of their digestive organs and interference with feeding (Jovanović 2017; Savoca et al. 2021; Wang et al. 2020). Plastics are not composed entirely of plastic polymers but contains numerous additives (e.g., fillers, coupling agents, plasticizers, colourants, stabilizers) which may leach out once ingested, possibly having indirect physical impacts on fish, as the decreased feeding or predatory performance, disturbed energy metabolism and inflammation in different organs, decreased mobility, growth, reduced body condition, and overall reduced performance (Kögel et al. 2020; Jovanović 2017; Markic et al. 2020).

In addition, plastic garbage absorbs possible persistent organic pollutants (POP) present in the water, such as pesticides, fertilizers and industrial chemicals, thus becoming potential carriers of these dangerous substances (Markic et al. 2020; Wang et al. 2020). These chemicals (including some with endocrine-disrupting properties) attached to the plastics can be liberated inside the fish and result in physiological damage to the organism (Gallo et al. 2018; Markic et al. 2020). For example, there are reports in which fish that had ingested microplastics had oxidative lipid damage in the brain, muscles, and gills (Barboza et al. 2020). The net consequence of microplastic consumption combined with high concentrations of exposure to associated chemical additives and contaminants, and habitat degradation are likely to alter behavior and survival rates of juvenile fishes given there are documented negative impacts on organ, organismal, and community levels, activity, olfactory threat cues and risk exposure behavior (Guven et al. 2018; Lönnstedt and Eklöv 2016; McCormick et al. 2020).

Microplastic ingestion is also related to the trophic level or feeding strategy. For example, the differences in distribution and composition of microplastics in different marine habitats are important factors influencing the probability of ingestion (Wang et al. 2021). Sathish et al. (2020) reported that species in shallow habitats had higher ingestion rates than species in the deeper oceanic habitats. In terms of feeding habits, the findings of Wang et al. (2021) indicate that benthivores ingest the highest abundance of microplastics with the greatest variety of polymer types. Feeding strategy also influences the intake of microplastics in fish. Planktivores have high probability of consuming microplastics directly from the environment, while piscivore consumption is expected via trophic transfer through prey or accidental ingestion (Walkinshaw et al. 2020). Fish that mainly rely on visual foraging cues ingest microplastic particles significantly more often and in higher numbers than species that mainly perform chemosensory foraging (Roch et al. 2020). Despite the increasing literature on marine plastic contamination, there are few studies that address the role of biotic factors on the ingestion of microplastics (e.g., Kibria et al. 2022; Markic et al. 2020; Roch et al. 2020; Sathish et al. 2020; Savoca et al. 2021; Wang et al. 2021). Therefore, increasing our knowledge on how ecological traits relate to the likelihood of consuming microplastic particles is key to understanding the human exposures that can occur through the consumption of species that are targeted by fisheries.

Plastic debris entails direct and indirect impacts on human activities and poses a clear cost to the economy and human wellbeing relating to the provision of sustainable and safe fisheries and aquaculture products (Beaumont et al. 2019; Mendenhall 2018). Concerns have been raised that the microplastics, along with adhered chemicals, pose production risks for fisheries, impacting food security and seafood safety (Du et al. 2020; Lusher et al. 2017). The negative consequences of microplastic pollution for fisheries production are based on the risks that microplastic contamination poses to commercial fish species (Walkinshaw et al. 2020).

Direct adverse effects on human health associated to human consumption of microplastic through the food chain are still controversial and not well understood (Barboza et al. 2018). However, it is possible that microplastic consumption has toxic effects as several chemical substances can be bioaccumulated by microplastic and could potentially pass from fish to humans (Du et al. 2020). Even low concentration, chronic exposures and intake at low concentrations can increase the threshold of hazardous chemicals that represents a potential threat to humans (Kögel et al. 2020; Sathish et al. 2020; De-la-Torre 2020). For instance, it is known that the plastic serves as a vector for the bioaccumulation of Persistent Bio-accumulative and Toxic Substances (PBTs)

(Rochman et al. 2013). In contrast to microplastic particles, PBTs build up in the tissues of organisms and accumulate up the food chain, leading to increased body burdens in higher trophic levels (Lusher et al. 2017). Furthermore, the most common additives used in the fabrication processes and reported in macro-and microplastic debris collected in environmental surveys are phthalates, bisphenol A and flame retardants (Hermabessiere et al. 2017). Some of these molecules can act as endocrine disruptors, and may contain toxic properties at levels ranging from 1000 to 500,000 mg/kg (ppm) (Gallo et al. 2018; Lusher et al. 2017). Research has shown that other chemical compounds present in plastics or adhered to microplastics, like residual low molecular weight styrenes, polyvinyl chloride monomer, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), oral contraceptive pills (OCPs), and pharmaceuticals, including their metabolites, could become carcinogenic, mutagenic, and endocrine disruptors after being uptaken (De-la-Torre 2020).

Consumption of microplastics thru seafood is likely to be particularly significant among those social groups that highly depend on fish as a source of protein and/or as a primary source of income. In developing countries, such as Mexico, a large proportion of coastal communities rely on small-scale fisheries as a means of income (e.g., financial resources), subsistence (e.g., survival needs), and protein intake (Cinner and Pollnac 2004; de Oliveira Leis et al. 2019), and generally, live with economic uncertainty and heterogeneous profits across the year (Coronado et al. 2020). Microplastics in fish species might, therefore, compromise fishers' income and health since fish is the main diet and a significant component in the regular food intake of thousands of families in coastal communities (Benítez and Flores-Nava 2019). In Mexico, approximately 70% of the artisanal fishing community face food insecurity and low living standards, derived from low income and low average wages (DOF 2020; Fernández et al. 2011). In this context, it is essential to consider the implications of the emergent pollution problems of microplastics on target species and the people who rely on them. Here, we first aim to characterize the presence of microplastics in species targeted by small-scale fishers and explore if the fish consumption of microplastic particles is associated with biological factors (as home range), to understand possible consequences that lead to the uptake of microplastic by fish. Second, we applied semi-structured interviews to small-scale fishers to examine, from a socio-environmental perspective, the potential social and environmental impacts of contamination by microplastics on the local communities. Since the possible presence of microplastic items inside of the main commercial fishes in the area, and the associated risks that may imply in the people that relies on the benefits of the fishing activity, an assessment of the social and environmental negative implications is relevant to conform an integral analysis of this global issue from a local perspective.

Materials and methods

This study was conducted in Puerto Morelos, Quintana Roo, a locality in a Mexican state that occupies the eastern portion of the Yucatan Peninsula (Melbourne-Thomas et al. 2011). The population in this locality has rapidly increased, from around 1000 habitants in 2000 to > 30,000 habitants in 2020 (INEGI). Small-scale fishing is a secondary activity that mainly provides seafood products to local restaurants, residents, and fisher households (Salas-Márquez et al. 2013). As in other coastal communities in Quintana Roo, small-scale fishers target multiple species with diverse fishing gears throughout the year.

The study consisted of two complementary approaches. First, we obtained fish samples onboard fishing vessels to identify and quantify microplastics in the gut content. This was conducted in the spring months of 2018 and 2019. Secondly, interviews with fishers were conducted between April and May 2021 to understand the local fishing dynamics and explore the possible social linkages of microplastic pollution.

Fishing gear and fishing seasons

We used data on three different fishing gears/methods, which were performed at different times based on the fishers' decision: (1) "hand line", a method that employs a nylon line with a weight and hooks mainly used in shallow waters and close to the coast, (2) "rosario line", that is similar to the hand line, but with a longer nylon line and with more hooks, from ten to twelve. This method usually targets red snapper (*Lutjanus* spp.; locally known as huachinango) and is deployed at waters depths (50 to 200 m). Hand line and rosario line use bait previously captured in shallow areas near the shore using cast nets (Salas-Márquez et al. 2013). Then, (3) "speargun" is a gear primarily used with SCUBA to capture lobster (*Panulirus argus*) but at the same time fish are captured inside holes or caves (Salas-Márquez et al. 2013). According to the use of fishing gears throughout the year, in this study two fishing seasons were considered, lobster fishing season (July to February) and fish fishing season (March to June). Depending on the fishing season, fishers used only used one type of gear per fishing trip.

Fish sampling and gut processing

Fish samples were collected onboard fishing vessels by one member of our research team (O. R-G). Fish collected ($n = 424$) were identified and measured (total length in cm).

We also recorded the fishing method and the season (see above). Once onboard each fish was dissected removing the digestive tract (from top of the esophagus to the anus) using scissors, scalpel, and forceps, and put it into a numbered glass vial. Samples were transported in a cooler to the laboratory (2 km away from the fishing pier) and stored at − 20 °C until further laboratory procedures. In the laboratory, the collected gastrointestinal tracts, compose of the stomach and intestine with their contents and wall, were washed with ultrapure Milli-Q water and stored in individual glass beakers. Then, the organic matter was digested using a hydrogen peroxide treatment. After digestion, each tract was transferred to a Petri dish and immediately covered to prevent possible contamination. The stomach contents of each fish were then observed under a stereoscopic microscope. The handling of the content was made with fine tweezers, a dissecting needle, and the use of ultrapure Milli-Q water to moisten the stomach contents and separate the non-natural particles following Neves et al. (2015). All the plastic items recovered from the samples were sorted and quantified according to their tactile resistance to physical contact, coupled with the absence of cell structure, sharp edges, and distinctive colors. This methodical approach culminated in the delineation of three shape categories: fragments (*i.e.,* broken small pieces), pellets (*i.e.,* granular and spherical particles), and fibers (*i.e.,* thin and elongated filaments).

From the 1069 suspected microplastic particles obtained from the gastrointestinal tract, 144 randomly selected particles were validated using (Fourier-transform infrared (FT-IR) at the Greenpeace Research Laboratories, University of Exeter. FTIR analysis was performed on particles and fibers representing the most common items in our samples and those that visually appeared to be different from the most common items. The samples were dried at 35 °C for 18 h and placed on a silver filter. The infrared absorbance from 650 to 4000 cm^{-1} with a resolution of 4 cm^{-1} was compared with spectra in the software database, with a similarity threshold of $> 70\%$. The infrared spectrum was processed and analyzed using a specialized program (Perkin Elmer Spectrum, 10.5.4.738). The plastics were identified through automated comparison combined with expert researcher judgment (including manual inspection of the spectra to verify the absolute and relative locations and intensities of peaks) and the use of commercial spectrum catalogs that included polymers, additives, solvents, and potential laboratory contamination materials. Re-evaluation by manual inspection, as recommended by Schymanski et al. (2021), was routinely performed as a crucial step in verifying the spectral matching. To ensure a working environment free of plastic contamination, all laboratory instruments and tools were washed with ultrapure Milli-Q water, cleaned with ethanol 70%, and checked under a stereomicroscope before use and in-between individual samples to prevent cross-contamination. Cotton laboratory coats and latex gloves, glass, and metalware were used during the whole procedure.

Quantitative analyses

All the data collected from the microplastic characterization were classified and sorted according to species, family, size (total length), species home range, fishing season, fishing method, and price per kg. Species home range was categorized sensu (Quimbayo et al. 2021) as Mobile: species that remain in area of more than 100 m^2 or traveling among different reef areas, and Very Mobile: species which frequently change reefs or travel large distances on the same reef daily. The species price (without considering the size) was recorded from the retail price published by the Cooperative of Fisherman in Puerto Morelos in May, 2021 (Table S1).

Differences in the number of microplastics between fishing methods, home range habitat, and economic price of fish were statistically compared using a Kruskal–Wallis test with a post hoc Dunn's test to determine significant differences among samples. The level of significance was set to $p < 0.05$.

Fisher interviews

Semi-structured interviews were applied to local members of the Fisheries Cooperative of Puerto Morelos on March and April 2021 to explore the possible social linkages of microplastic pollution for fishers. This type of interview works for those interested in interviewing people with little time or who are used to efficiently managing their time (Vela 2001). The Puerto Morelos cooperative comprises 11 members (people with the legal right to conduct fishing activities and vote on how the cooperative is run) and 30 assistants (crew who join the cooperative members onboard when they go to fish) (Salas-Márquez et al. 2013). The interviewees were selected only through the cooperative partners as they are the ones with more experience and local knowledge. Given the prevailing pandemic restrictions, participation in this research was entirely voluntary, with participants having the option to engage in the survey. Five partners agreed to be interviewed. Each fisher possesses over two decades of experience working with the cooperative.

The semi-structured interview included three main topics: (1) the characterization of the small-scale fisheries in Puerto Morelos in terms of the seasonal use of fishing gears according to fishing seasons, the profitability of the activity, and their physical effort. (2) The level of dependency from the fishing activity in terms of income and subsistence. (3) Current knowledge of microplastic pollution. Details of the structure and content of the interview are provided in the supporting material. The data collected from the interviews were codified through the identification of key points in the narrations that belongs to each category of topics described before. Therefore, key points were compared among the participant's answers to find similar or dissimilar ideas.

Results

Microplastics in commercial fish in Puerto Morelos

A total of 424 individuals of commercial fish, belonging to 29 species and 9 families, were obtained, and analyzed. Fifty eight percent of individuals were caught with hand line, 35% with speargun and 7% with rosario line (Table S1). Regarding the number of fish captured on each season, 278 individuals were recorded when the lobster was not in season and 146 in the lobster season.

From the 1069 isolated suspected microplastic particles, a random subsample of 144 microplastic items was characterized according to the polymer type using FTIR spectroscopy, resulting in the presence of modified cellulose as the major material in the samples, largely represented by cellophane (49%). Synthetic polymers were identified in 37% of the analyzed samples, but also by polyester, ethylvinylacetate, nylon, polystyrene, polypropylene, and polyacrylate (Table S1). The rest of the subsamples (14%) were discarded as result of non-clear match in the FTIR verification.

The most prominent species in this study were *Lachnolaimus maximus* (116), *Lutjanus vivanus* (75) and *Lutjanus synagris* (61). Across all species the general ingestion rate of microplastic items was 57%, where 1069 pieces were found in 241 fish, with an average plastic load of 2.5 items per fish (Table S1). The families with more microplastics were Carangidae with a mean of 4.09 ± 1.28 pieces ($n = 31$), Lutjanidae with a mean of 3.01 ± 0.40 pieces in 173 individuals, Ballistidae (2.8 pieces/family ± 0.59 $n = 26$) and Serranidae (2.4 pieces/family ± 1.38 $n = 7$) (Fig. 1a). Regarding the home range, 380 individuals corresponded to mobile home range habitat, meanwhile 44 to very mobile. Very mobile individuals ingested significantly higher number of microplastics ($df = 421$, $F = 6.486$ $p = 0.015$) (4.14 pieces/category, mean value) compared to mobile (2.35 pieces/category, mean value) species (Fig. 1b). With respect to the fish captured with different fishing gears, we found that individuals caught with the hand line tend to have significantly more microplastics than those tended caught with rosario line and speargun methods ($df = 423$, $F = 10.5$ $p = < 0.001$, *pos hoc* A (hand line) B (speargun) $p = < 0.001$ A (hand line) C (rosario line) $p = 0.018$; Fig. 2a). The average length of fish per fishing method was 30 cm (speargun), 32 cm (hand line), and 37 cm (rosario line). Furthermore, the price selling fish caught with the hand line was the lowest but statistically significant difference only with the speargun method ($df = 423$ $F = 4.34$ $p = 0.0143$ post hoc: A (hand line) C (speargun) $p = 0.0124$) (Fig. 2b). Therefore, when the fishers use the hand line, they primary caught low-value species among the entire fish that they can capture, and those fish in this study contained more microplastics in their digestive tract (Fig. 3).

Small-scale fisheries characteristics in Puerto Morelos

Based on the interviews, we provide a characterization of the artisanal fisheries' dynamics in Puerto Morelos through the fishers' perspective. Three topics were considered to elaborate the description. First related to the dynamic and characteristics of fishing, we confirmed the existence of two fishing seasons based on the lobster season, which did not change, due to fishing regulations in the region. The first one is the season of fish that starts in March until January. Therefore, during the lobster season (July to February), the primary gear used is SCUBA in which, the speargun is the

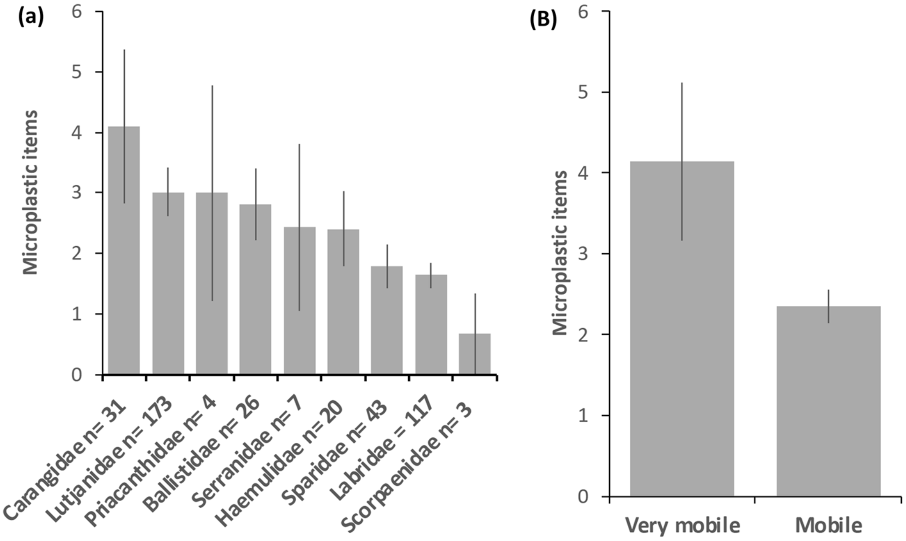

Fig. 1 (**a**) Families of commercial fish in Puerto Morelos with presence of microplastic items (n = number of individuals belonging to each family). Error bars represent standard error. (**b**) Microplastic items average ingestion across home range habitat, very mobile ($n = 44$) and mobile ($n = 380$). Error bars present standard error

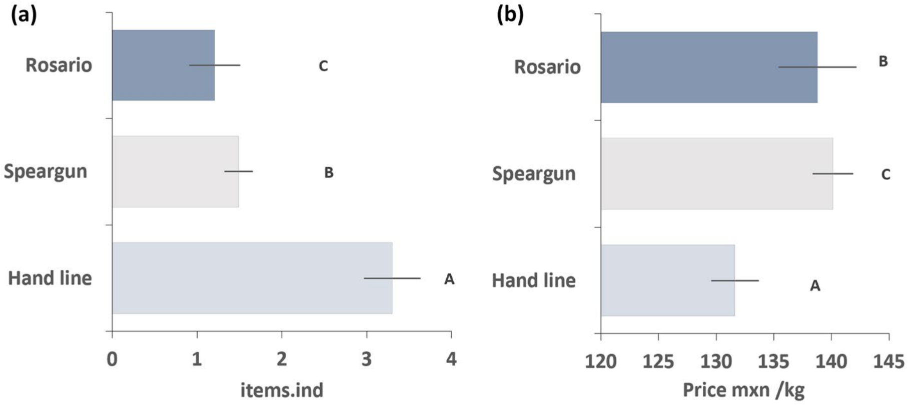

Fig. 2 (**a**) Average uptake of microplastic items by individual according to three different fishing methods (rosario line $n = 29$, speargun $n = 149$, hand line $n = 246$). Error bars present standard error. (**b**) Fish average coast of public selling related to three different fishing methods. Error bars present standard error

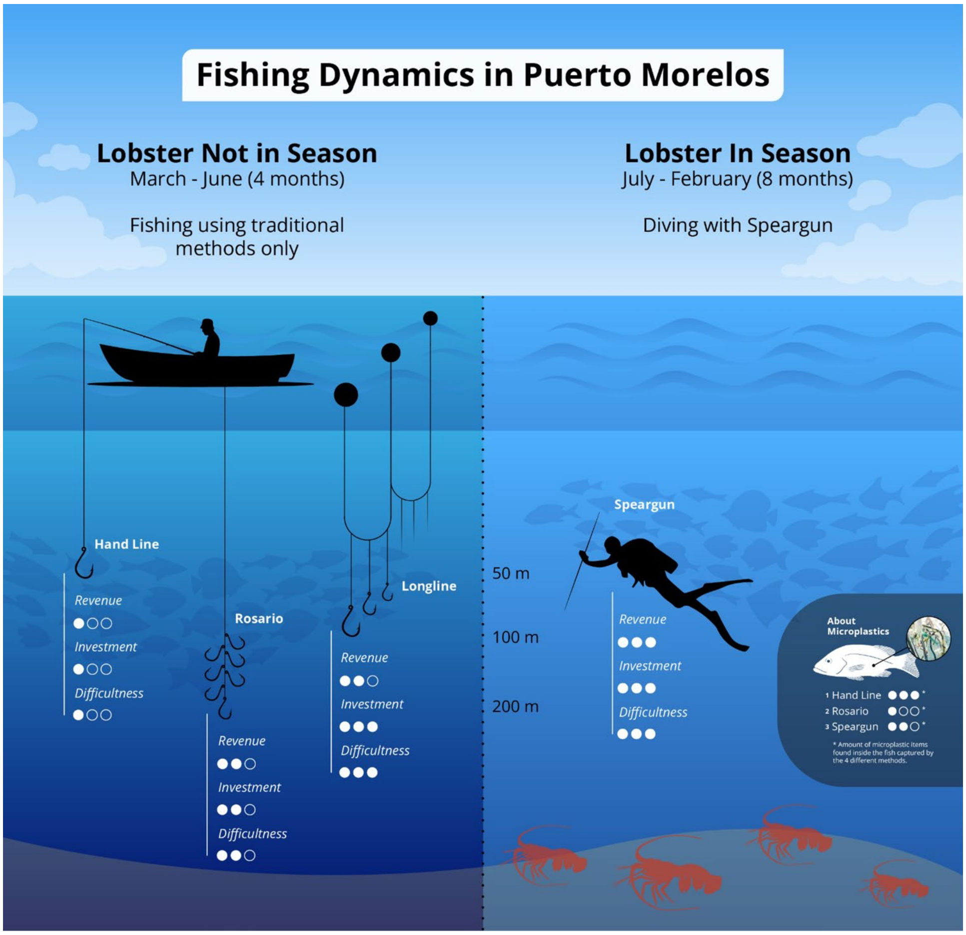

Fig. 3 Fishing characteristics in Puerto Morelos based. The two main fishing seasons in Puerto Morelos: fish season (left) and lobster season (right). The speargun is the main method used for the Lobster season, while hand line, rosario line and longline are used during fish season. Please note data on fishes captured with longline were not included in this study. Revenue represents the profit in a scale from one (low revenues) to five (high revenues) dots. The economic investment related to each fishing method, is illustrated with major number of dots equal to higher investment in the activity. Difficulty represents the physical effort, as high, medium, and low according to the number of dots collocated. The white fish represents the amount of microplastic items within fishes caught from each technique (See Fig. 2)

primary gear to use. According to the narrations, lobster season is the most preferred mainly because the high revenues that represents the capture of this species (*P. argus*) as well as fish with high economic value such as *L. maximus*.

When asked about the type of substrate to conduct fishing activities, all interviewees referred to “rocky bottoms” as the preferred substrate indistinctly of the fishing gear used. Two fishers refer to the term reef together with the rocky bottom term. Regarding the species captured during the fish season, the five fishers agreed that the most commonly caught species are snappers (*Lutjanus* spp.) and groupers (Serranidae). While in lobster season, in addition to snappers and groupers, the Hogfish (*L. maximus*) was also identified as a target species. The interviewees identified the above-mentioned taxa as the most profitable species, while haemulid fishes such as *Ocyurus chrysurus* and *Haemulon* spp. were identified as low-value species. According to the five interviews, four fishing techniques are used throughout the year with marked differences in revenue, economic investment, and skills needed. The speargun consists of capturing fish selectively while seeking lobster on SCUBA (Fig. 3). According to the fishers, this method is the most profitable due to the lobster but also gives the possibility to target the most profitable individuals' fishes. The speargun activity was classified as of medium economic investment but highly difficult.

Three fishing methods are implemented during the fish season: the longline, the rosario line, and the hand line (Fig. 3). As stated by the fishers, the hand line is the easiest method to work with. It requires the lowest economic investment, but the species caught with this method are usually small and have the lowest monetary value. The rosario line represents the gear with the greatest difficulty and costs (gasoline). Fishing with this gear type is conducted far from shore and requires more equipment (longer lines, more hooks and weights). Fishers conceive the revenue related to rosario line as a medium level despite the high price of Red snappers, mainly due to high costs associated with this gear. Finally, the longline is the primary method used in this fishing season. According to the narrations, this fishing technique represents the most significant physical effort. The revenue also is placed in a medium level while the economic investment is equal to the method of the speargun. Longline was part of the narrative through the interviews; however, none of the fish analyzed in the current study had been captured with this technique (Fig. 3). Furthermore, the interviewed fishers expressed that fish season is more physically demanding because of the longline.

Through the interviews fishers explained that fishing is their only source of economic income, and they mentioned that taking home fish is a normal practice among fishers, but normally the fish that use for subsistence is the fish with less economic value. Appreciation of the microplastic pollution problem among all interviewed fishers was not noted; nonetheless, the plastic problem on a macro scale was constantly mentioned. Their answers highlighted the adverse impacts of plastic waste, particularly its effects on occupational performance, such as engine complications and concerns regarding the condition of areas where their products are delivered. However, when explicitly prompted about the potential presence of pollution within the fish they catch, all the interviewees were noticeably surprised. They hypothesized the potential negative impacts and discussed the environmental conditions that could lead to such contamination.

Discussion

In Puerto Morelos, the consumption of microplastics by fish caught through traditional fishing gear correlates with species mobility but the microplastic load also depended on the type of fishing gear used. Those with a wide home range had a higher load of microplastics than fish with a small home range but also seemed to be related to the fishing method. Fishes captured with hand line in shallow waters near the coast had significantly more microplastics in their guts than those caught in deeper water further from the shoreline (caught with rosario line), or those individuals of generally large size and from valuable species targeted selectively with the speargun. The observed differences in microplastic content on target species are likely to be transferred to humans in a non-random fashion. Fish with high microplastic content had the lowest market price and were generally used for self-consumption or sold to local inhabitants. This work implies that, although marine macroplastic litter is a widely recognized issue, microplastic pollution in commercial fish might represent a bigger concern for fishers and local people than they realize because they are consuming the lower quality species that have a high microplastic burden.

In relative terms, we found high load of microplastic on fish species with notable commercial value and characterized by being a significant component of the landings from small-scale fisheries in the Caribbean with species playing a major role as predators in reef ecosystems (e.g., Carangidae and Lutjanidae; Freitas et al. 2011; Manooch and Haimovici 1983; Mendoza-Portillo et al. 2020; Luckhurst et al. 2000). Microplastic items were found inside of the guts belonging to important commercial fish species in Puerto Morelos. Fifty-seven percent of the individuals examined had microplastics in their digestive tract, with a plastic load of 2.5 items per fish, similar loads have been obtained by other studies (Barboza et al. 2020; Marckic et al. 2018; Neves et al. 2015; Sbrana et al. 2020; Wang et al. 2021).

Recognizing the critical importance of refining and enhancing microplastic characterization, it is imperative to highlight our rigorous adherence to methodological standards in the identification of the 1069 particles. Thus, although these pieces are denoted as potential microplastics, each one exhibited discernible traits and features pertinent to microplastic classification, including resistance, shape, and color. Our analysis of the random subsample of microplastic analyzed with the Fourier transform infrared spectroscopy (FTIR) pointed out that modified cellulose was the major material present in the samples (49%). A similar proportion of microplastic type have been reported in other studies. For example, Macieira et al. (2021) found 77% of the microparticles matching with cellulose origins. Although modified cellulose might instinctively be considered as potentially less harmful than other types of manufactured materials, such as conventional plastics, there is a need for caution as cellulose that has been dyed and extruded can no longer be considered to be an entirely natural material. As yet, little is known about the degradation or effects in marine environments of this modified cellulose. Nonetheless, the lack of familiarity with, and of information relating to, the prevalence, fate, and impact of artificial cellulosic microparticles often leads to an imbalance in primary concerns towards plastic polymers only (Suaria et al. 2020).

It is difficult to identify the factors that determine ingestion based only of the items found in the gastrointestinal tract. Hence, the underlying mechanisms of how these particles were ingested are largely unclear (Macieira et al. 2021; Roch et al. 2020). Nonetheless, we found significant differences among the microplastic ingestion on two fish habitat categories, mobile and very mobile, the latter with significantly more microplastic particles. From our results we inferred that very mobile species are exposed to a broad range of conditions (i.e., habitats) and are more susceptible to ingesting microplastic than those with more restricted movement or habitat use. This coincides with studies where benthopelagic fish ingested plastic significantly more frequently than benthic and pelagic fish, suggesting that benthopelagic species feed in a broader range of habitats or benthic species resulting in a greater exposition to more sources of plastic contamination (Markic et al. 2018). In addition to the biological or behavioral attributes of the organism, other environmental or biotic factors might also determine the intake of microparticles. For example, environmental availability of plastic particles is a clear factor that may influence the different concentrations of debris among locations and therefore likelihood of consumption by fish (Cardozo-Ferreira et al. 2021). In our study area, little is known about plastic contamination and the dynamics that local conditions might influence the microplastic inputs. Yet, the rapid increase in coastal development across the region and the high presence of tourism (e.g., in 2019, the Mexican Caribbean received > 16 million visitors; DATATUR 2022) might represent an important source of plastic pollution in the area. In this context, investigating how biological traits and the ecological and anthropogenic context are linked to microplastic consumption will be crucial to determining the impacts of microplastic pollution on fish species and their connection with human consumption.

The risk of microplastic ingestion can be high in coastal communities that rely on the seafood for their diet (Landrigan et al. 2020). Fishers in Puerto Morelos use various methods to fish, mostly owing to the fishing seasons marked by the lobster seasonal closure. When we analyzed the microplastic uptake data by fishing methods, it was evident that fish captured with hand line had significantly more microplastics compared with those captured with rosario or speargun. Rather than an effect related to the fishing method per se, this result might be explained by the inherent differences of the species targeted by the method (i.e., home range as discussed earlier) or by the characteristics of the areas where fishers deployed each fishing method (e.g., hand line is used on in shallow rocky bottoms near the shoreline). Note that the fish caught using hand line method not only showed high presence of microplastics in the gut, but also had the lowest economic value. In addition, hand line technique was described as a technique used in a season marked by a complicated economic context. Therefore, we could say that the microplastic pollution in commercial fish on Puerto Morelos might represent an additional, but not well perceived, problem on top of the difficult times that the fishers already describe for those months of the year. Currently we cannot measure the dimension of this problem in the medium and long term but analyzing it from a local perspective acquires relevance to understand the vulnerability of traditional fisheries.

Understanding fishery dynamics from the fishermen's perspective is essential for addressing the potential social implications of this issue. The fishery description presented in this study has revealed themes that align with our observations in microplastic characterization. In this context, important topics emerge from the dialogues made with fishers. Firstly, the fishers explained that fishing is the only source of income. And second, it was remarked the common practice of taking fish to home to feed their families, and these fish have the less economic value (mainly caught with hand line method). Although, our social interviews are not conclusive and there is need for future effort to fully understand the social implications of our findings, there are issues worth to highlight. First, microplastic ingestion, as reported in the literature (e.g., Barboza et al. 2020; Guven et al. 2018; Jovanović 2017; Lönnstedt and Eklöv 2016; Markic et al. 2020), and the probable presence of marine debris in their fishing areas, threatens the primary subsistence economic activity of fishers in Puerto Morelos. Second, the uptake of microplastic items by commercial fish might represent a human health issue because these species are for human consumption. However, the human health consequences of microplastics consumption are controversial. The main concerns with microplastics that are consumed are that they contain potentially hazardous chemicals like plastic monomers and additives or adsorb toxic pollutants from the environment, harmful microbes, and algae vectors for human disease that all are being able to reach humans along the food chain (Garrido Gamarro et al. 2020; Landrigan et al. 2020; Lionetto and Esposito Corcione 2021). Nonetheless, there is no robust evidence yet that the safety of marine products is compromised by microplastics (Garrido Gamarro et al. 2020). In the absence of sound evidence, further understanding of the impacts of microplastics on seafood is urgently needed.

Regardless of the discrepancy on the consequences for human health owing to the microplastic uptake from fishing resources, fishers in Puerto Morelos take home fish with a high rate of microplastic items in their guts compare to other species, as they select for self-consumption the fish with the lowest economic value. This is particularly relevant if we consider that the number of commercial species that consume plastic has increased exponentially in recent years (Savoca et al. 2021). Given the economic and ecological importance of these fish groups, and the rest of the families and species of fish with microplastic inside, major efforts to understand the implications between microplastic uptake in commercial fish species and their health outputs as well their possible socioecological implications must be taken. In particular, we highlight the pressing need of further interdisciplinary research and solutions to the plastic pollution that focuses not only on the effects on the organisms themselves, but also on the health implications for humans who consume these organisms (Courtene-Jones et al. 2021; Rist et al. 2018). This is relevant due to the outcomes that science communication may have in a local or global context. In conclusion our findings show that the presence of microplastics in the commercial fish guts of Puerto Morelos emerge possible environmental and social implications that might be cumulative in the future. These issues might point out directly to fishers and their families firstly, but also to the society that is involve in the local fishery dynamics. Efforts to understand and tackle this problem have been more common every day, nonetheless, integrate the environmental and the social aspects from a local perspective of the problem must be a priority in terms to analyze the possible causes and solutions in an integrated way.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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