*microplastics*

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# Presence of Microplastics in the Vaquita Marina Protection Zone in Baja California, Mexico

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**Abstract:** Microplastics (MP) have been evidenced in marine and coastal areas worldwide, including the Gulf of California in Mexico, where the Vaquita Marina refuge area is located, which in turn borders the protected natural area Alto Golfo de California y Delta del Rio Colorado. This research aimed to determine the concentrations of microplastics in the Vaquita protection zone, analyzing samples of ten transects of surface water and samples in the sand of five beaches on the coast surrounding the Vaquita protection polygon. The total concentrations of MP in the surface water transects were from 0.000 to 0.020 MP/m$^3$ and their most recurrent characteristics were fragments (69.0%), the chemical composition of polyethylene (60.0%), the blue color (39.0%) and a size of 2.1–3.0 mm (31.0%). While for the beaches, these corresponded to averages ranging from 28.2 ± 36.4; 17.6 to 200.7 ± 77.9; 193.7 MP/m$^2$, the most common characteristics of MP from beaches were filaments (33.2%), PE (32.3%), white (28.0%), and a size of 4.1–5.0 mm (32.0%). The results suggest that part of the MP on the beaches and in the Vaquita Marina refuge area could come from urban areas such as the Gulf of California and activities such as fishing. It is recommended to study all the transects of the Vaquita Marina polygon and more beaches surrounding it in different seasons to better understand the status of MP pollution.

**Keywords:** fragments; Gulf of California; natural protected area; polyethylene

**Citation:** Cruz-Salas, A.A.; Alvarez-Zeferino, J.C.; Tapia-Fuentes, J.; Lobato-Rocha, S.L.D.; Vázquez-Morillas, A.; Ojeda-Benítez, S.; Cruz-Sotelo, S.E. Presence of Microplastics in the Vaquita Marina Protection Zone in Baja California, Mexico. *Microplastics* **2023**, *2*, 422–436. https://doi.org/10.3390/microplastics2040031

Academic Editor: Nicolas Kalogerakis

Received: 17 November 2023
Revised: 8 December 2023
Accepted: 13 December 2023
Published: 16 December 2023



## 1. Introduction

Plastic pollution represents a significant threat to marine ecosystems; it has been estimated that 80% of the plastic waste that is disposed of in the ocean is land-based, and each year about 8 million tons reach the sea [1], mainly through drainage systems, water bodies with connection to the sea, and coastal tourism [2]. Meanwhile, 20% of the remaining waste originates from marine activities such as commercial fishing and recreational, commercial, military, and research activities on vessels, in addition to activities on oil and gas platforms, which generate both solid waste and waste pertaining to their specific activities [3].

Plastics that end up in the sea have the potential to turn into microplastics (MP), particles with sizes smaller or equal to 5 mm that are characterized by being highly hydrophobic and having a large surface area, therefore having the capacity to adsorb other chemical contaminants and pathogens that can subsequently be transported to different marine ecosystems [4,5], leading to different potential effects.

A synthesis on the status of pollution in the Gulf of California, carried out by Páez-Osuna et al. (2019) [6], reveals the scarce but transcendental information available about plastic contaminants within the region: the presence of MP from plastic bags and nylon ropes in the diet of Chelonia mydas turtles, MP in the surface water of Bahía de la Paz (0.00–0.14 pieces/$m^3$), and the detection of exposure of gulf whales to persistent organic compounds, including phthalates, which are chemicals that are often added to plastics as additives. This type of background information is relevant in terms of the impacts experienced by marine ecosystems, and the organisms that comprise them, especially those in a priority conservation status.

The inherent activities of the Gulf of California, like fishing, tourism, and agriculture [7], can lead to microplastic contamination, a situation that is even more exacerbated considering that the region is subjected to various pressures, like fishing resource overexploitation and illegal fishing, which occurs especially in the Upper Gulf of California, home to endemic species such as Totoaba fish (*Totoaba macdonaldi*) and Vaquita Marina cetacean (*Phocoena sinus*), a marine mammal [8].

Vaquita porpoises also experience other threats to their survival, such as inbreeding resulting from their small population, pollution of their habitat, and decreased flow of the Colorado River [8]. Microplastics, as emerging contaminants, could constitute another important pressure factor for the subsistence of vaquita porpoises, taking into account both licit and illicit economic activities within the region.

The consumption of microplastics by marine mammals is a known condition, and it is reported that said fauna usually consume significant amounts of plastics through the trophic route and via direct consumption of seawater or sediments [9]. In addition to finding these types of particles in the stomach, gastrointestinal tract, and feces of these organisms, concern has recently arisen about the translocation of MP in the interval of 24.4–1387 µm, particularly to the lipid-rich tissues that these animals usually have [10], which is highly worrying because they can favor the bioaccumulation of these particles and the contaminants that adsorb to them.

The effects of MP when ingested can not only be physical, by reducing the energy reservoirs, growth, and fecundity of the species that ingest them, they can also be chemical, since the substances adhered to MP, such as plasticizers, additives, persistent organic compounds, and heavy metals can bioaccumulate and induce damage to organisms. The toxicity of these compounds can even affect the entire food chain with uncertain consequences [11].

In light of the presented scenario, in which the vaquita porpoises could be ingesting MP as part of their diet, either directly by food consumption or indirectly by water ingestion, and in turn accumulating MP and the contaminants attached to them, investigations regarding plastic pollution and its effects within the habitat of the vaquita porpoise are of great importance as part of the efforts towards its conservation.

The objective of this study was to investigate the presence of microplastics both in the vaquita protection zone, analyzing samples of surface water, and in the sand of the beaches on the coast surrounding the vaquita protection polygon.

## 2. Materials and Methods

This section presents the methodology followed for sampling microplastics both in the surface water of the Vaquita Marina Protection Polygon and in sand from five beaches located on the coast of the Gulf of California (Figure 1). Likewise, the steps followed to process the samples in the laboratory are presented.

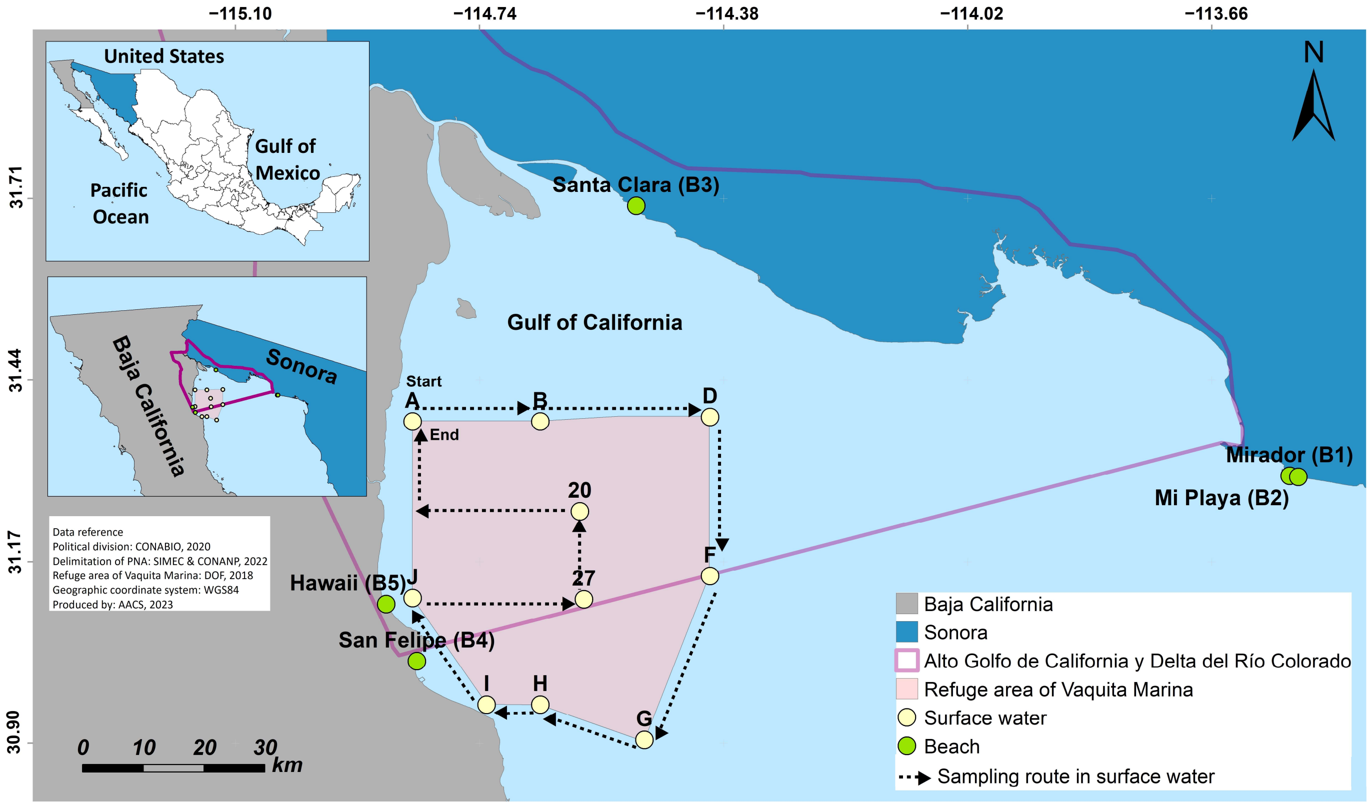



**Figure 1.** Location of study zones, transects of surface waters in the Refuge area of Vaquita Marina and points in sandy beaches.

## 2.1. Microplastics Sampling

Sampling of microplastics in surface water was carried out in June 2018, while those corresponding to sandy beaches were conducted in April 2019.

### 2.1.1. Superficial Water

The Vaquita Marina Refuge area comprises an irregular polygon that limits to the west with Mexicali, Baja California, and north, east, and south with the waters of the Upper Gulf of California. Its surface is 1841 km$^2$, of which 1307 km$^2$ is part of the Alto Golfo de California y Delta del Río Colorado Biosphere Reserve, a Protected Natural Area [12]. The sampling was carried out aboard a Defender BR-40-type vessel belonging to the Secretaría de Marina (SEMAR). To obtain an overview of the presence of microplastics in the refuge area, surface seawater samples were taken following the route of eight of the vertices of the polygon and two interior points.

Water sampling was done by adapting the methodology proposed by Ferreira et al. (2020) [13] and Goswami et al. (2020) [14]. A nylon plankton net model LaMotte 1063 (LaMotte Company, Chestertown, WA, USA) was used with a pore opening of 0.153 mm, lower and upper base diameters of 0.032 and 0.3 m, respectively, length of 0.9 m and a volume of approximately 0.0948 m$^3$ (94.8 L). The plankton net was placed behind the boat (stern), secured with a 30-m rope, and the opening of the mouth was submerged subsurface (0.1–0.2 m depth) the entire time. The route was carried out at an average speed of 3 knots for 30 min; after each collection, the net was rinsed from the outside to the inside with deionized water, and the samples were collected in removable 50 mL tubes. Subsequently, the samples were placed in a sieve (W.S. Tyler, Mentor, OH, USA) in a number 30 stainless steel mesh (0.59 mm opening) to reduce volume, and they were kept in aluminum foil and airtight bags. The volume of filtered water was obtained using the speed of the boat, the sampling time, and the dimensions of the net.

2.1.2. Beach Sand

Five beaches located within the Alto Golfo de California y Delta del Río Colorado Biosphere Reserve area were chosen. Mirador (B1) and Mi Playa (B2) are in the municipality of Puerto Peñasco, in the state of Sonora; recreational activities such as walking, fishing, and camping are carried out on both beaches. Santa Clara (B3) is a beach located in the municipality San Luis Río Colorado in the state of Sonora; its predominant activity is fishing, however, depending on the season there is also usually a high tourist influx. Finally, Hawaii (B4) and San Felipe (B5) beaches are both in the municipality of San Felipe in the state of Baja California; in the case of Hawaii beach, it is located approximately 10 km from the municipal seat. In front of both beaches is the Vaquita Marina Refuge area, fishing is the predominant activity in the area.

The methodology followed was that proposed by Alvarez-Zeferino et al. (2020) [15]. On each beach, the high tide line was located, and parallel to it, a 100 m transect was delimited with the help of a rope, which was attached to the sides with stakes. Subsequently, ten random points were selected, and a cylindrical stainless-steel sampler (ø = 20 cm and height of 5 cm) was buried in each of them until its upper edge was at the level of the sand surface. A metal sheet was slid at the bottom of the sampler with which the sample was sectioned, the sand was weighed and finally passed through a stainless-steel mesh (W.S. Tyler, Mentor, OH, USA) with an opening close to 1 mm to make a volume reduction. The sand retained on the sieve was stored in aluminum foil and kept in zip-lock bags.

## *2.2. Extraction of Microplastics*

This section describes the procedure followed to extract the microplastics present in seawater and beach sand.

2.2.1. Surface Water Samples

The samples were dried at 60 °C for 24 h; then they were subjected to oxidation with 30% $H_2O_2$ (J.T.Baker®, Phillipsburg, NJ, USA) for 3 h to eliminate the organic matter present. The resulting solution was vacuum filtered with Millipore equipment (Millipore Corporation, Burlington, MA, USA), using cellulose membranes with a diameter of 47 mm and a pore size of 8 µm [16,17]. The present MP were extracted manually with the help of dissecting forceps; the particles were rinsed with deionized water, dried with absorbent paper, and placed in glass Petri dishes.

Only the particles in which there was doubt whether they were MP or calcareous material were added to an acid solution (0.5 N HCl) (J.T.Baker®, Phillipsburg, NJ, USA) [18].

2.2.2. Beach Sand Samples

The process of extracting microplastics from beach sand was adapted from what was carried out by [18]. Each sand sample was weighed to obtain the data on a wet weight, subsequently dried at 60 °C for 48 h and weighed again to obtain the dry weight. The dry sand was sieved into a 1.13 mm mesh, and the retentate fraction was subjected to floatation tests with a saturated solution of $CaCl_2$ (J.T.Baker®, Phillipsburg, NJ, USA) of 1.5 g/mL density, in a volume three times the volume of the sample [19]; the solution was stirred manually for 10 min and allowed to sit for about two hours (until the supernatant had no sand present). Floating particles were removed with dissecting forceps, rinsed with deionized water, dried with absorbent paper, and placed in glass Petri dishes. As with the surface water samples, tests were also carried out on the sand samples to rule out false positives.

## *2.3. Quantification and Classification of Microplastics*

MP particles of all samples were counted to obtain concentrations in pieces of $MP/m^3$ for water samples, in pieces of MP/kg of dry weight, and in pieces of $MP/m^2$ for samples of beach sand. Likewise, MP were classified by type (the spherical shape is not common but in Mexico it corresponds to ammunition for toys, while filaments refer to pieces of rope or nets) [18], color, size, and chemical composition; the size of each MP was determined with the help of a millimeter sheet, and the chemical composition was analyzed by Fourier Transform infrared spectroscopy (FTIR), in a Spectrum Two FT-IRL-160000A, 160000F Perkin Elmer, (PerkinElmer, Bridgeport, CT, USA). The measurements were done in the 400–4000 $cm^{-1}$ range, with a resolution of 4 $cm^{-1}$ and 32 scans.

### *2.4. Measures to Avoid Cross-Contamination*

It is essential to mention that in this work, large microplastics are being studied, with a size between 0.59 mm and 5.0 mm, which are visible to the naked eye, which is why the particulate material present in the air is ruled out as cross-contamination indoors and outdoors (during field and laboratory work). However, the following measures were taken to avoid cross-contamination and thus overestimation of the results: use of non-plastic materials and utensils (for example, glass and stainless steel) during sampling and extraction of microplastics; washing and drying, in an oven, of the material prior to use; and cleaning the work area, before use, with alcohol and absorbent paper [20,21].

## 3. Results

### *3.1. Presence of Microplastics in Superficial Water*

The concentrations of MP in the surface water samples were determined from the volume of water filtered through the network at each sampling point; the results are presented in Table 1. It is observed that transects I-J and J-27 had higher concentrations, with 0.020 $MP/m^3$ in each case; these areas are close to the town of San Felipe, which may indicate that the particles come from terrestrial activities. For its part, the lowest concentrations corresponded to transects F-G, 27-20, and 20-A, with 0.005 $MP/m^3$ at each one. It is also important to mention that in Vertices A-B, B-D, D-F, and G-H there were no microplastics.

**Table 1.** Microplastics concentration in surface water, per sampling point, in terms of MP pieces by volume.

| Transect | $MP/m^3$ |
|---|---|
| A-B | 0.000 |
| B-D | 0.000 |
| D-F | 0.000 |
| F-G | 0.005 |
| G-H | 0.000 |
| H-I | 0.010 |
| I-J | 0.020 |
| J-27 | 0.020 |
| 27-20 | 0.005 |
| 20-A | 0.005 |
| Average | 0.007 |
| Standard Deviation | 0.008 |

In relation to the characteristics of the MP found in the surface water of the Vaquita Marina polygon (Figure 2), the most common form was fragments (69%), a chemical composition of PE (60%), blue color (39%) and a size range of 2.1–3.0 mm (31%).

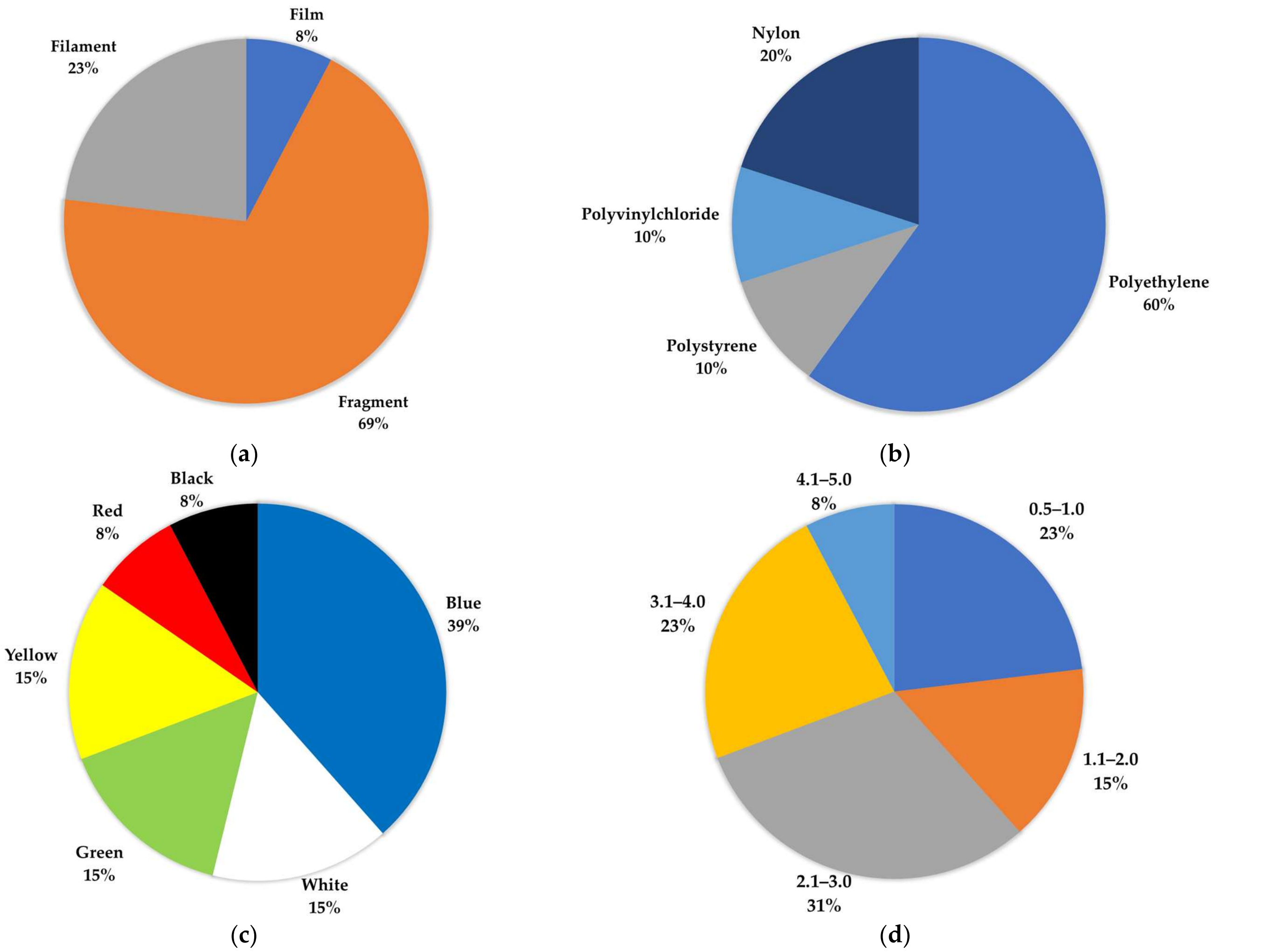



**Figure 2.** Classification of microplastics in superficial water (**a**) shape, (**b**) polymer, (**c**) color, and (**d**) size.

### *3.2. Presence of Microplastics in Beach Sand*

On the other hand, in the five sampled beaches, the presence of microplastics was found on each beach (Table 2); the beach with the highest concentration was Hawaii, with 200.7 MP/$m^2$, and the lowest was Mirador, with 28.2 MP/$m^2$. In general, the beaches where fishing activity is relevant had the highest concentrations (beaches B3, B4, and B5; Santa Clara, San Felipe, and Hawaii).

**Table 2.** Microplastics concentration in beaches, in terms of MP pieces by area and dry weight of MPs. Value average with deviation standard and median.

| ID | Beach | MP/$m^2$ | MP/$kg_{dw}$ |
|---|---|---|---|
| B1 | Mirador | 28.2 ± 36.4; 17.6 | 1.2 ± 2.5; 0.0 |
| B2 | Mi Playa | 38.8 ± 48.3; 35.3 | 0.9 ± 1.3; 0.6 |
| B3 | Santa Clara | 45.8 ± 64.4; 17.6 | 1.7 ± 1.9; 115.5 |
| B4 | San Felipe | 91.5 ± 50.3; 70.4 | 1.4 ± 0.8; 1.1 |
| B5 | Hawaii | 200.7 ± 77.9; 193.7 | 3.5 ± 1.5; 3.2 |

The points of highest concentration for both the surface water samples (Transects I-J and J-27) and the beach sand samples (Hawaii and San Felipe beaches) are located near the port of San Felipe, which suggests that the MP present may be associated with urban areas because said town has a population of around 17,000 inhabitants, which is the largest in the region [22]. In addition to this, San Felipe is a port with intense fishing activity, which is one of the main economic sources of social participation [23]; however, the development of this activity could generate microplastics from fishing nets and gear, either during its use or its wear and tear when abandoned.

The most common shapes globally were filaments and fragments (33.2% and 23.2%, respectively). The three beaches that showed this trend were B3, B4, and B5 (Figure 3), which have significant fishing activity.

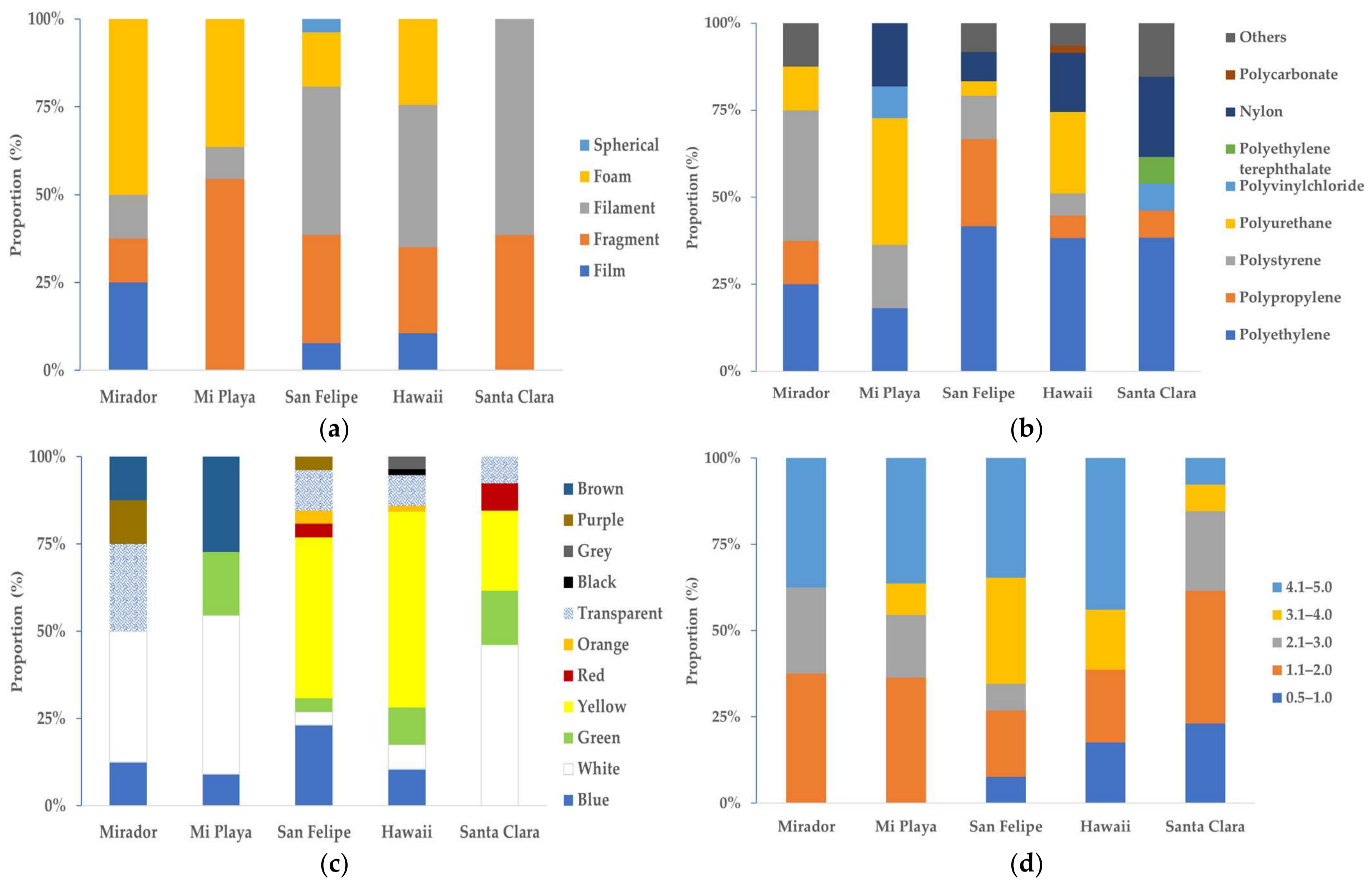



**Figure 3.** Classification of microplastics in sand beaches: (**a**) shape, (**b**) polymer, (**c**) color, and (**d**) size.

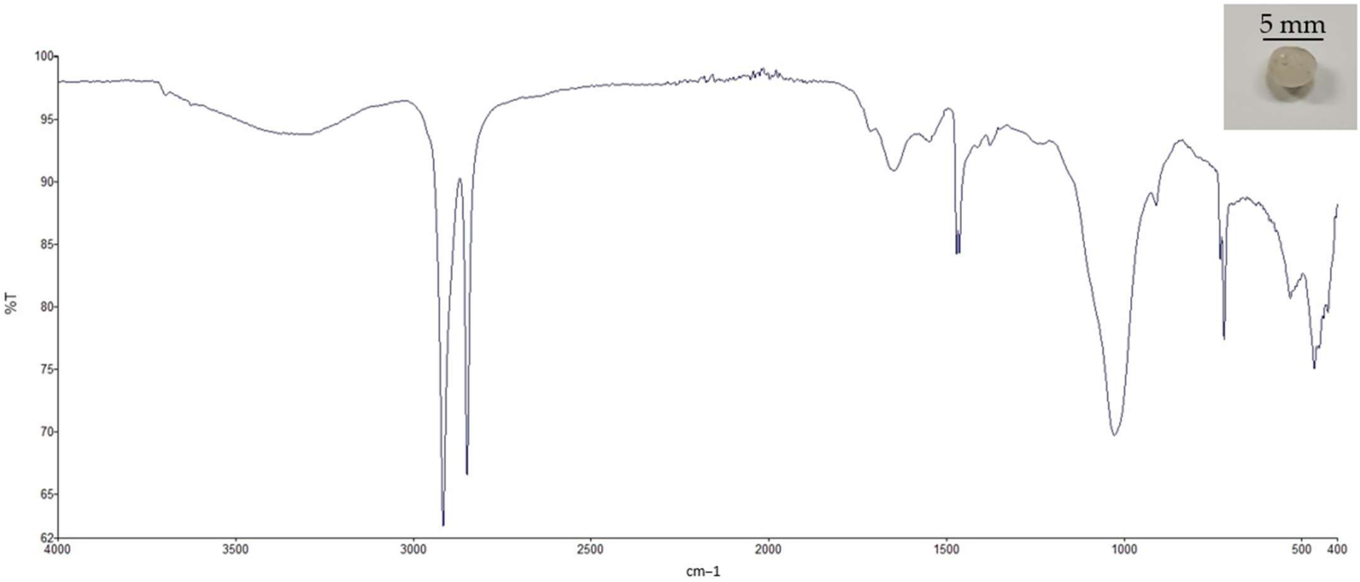
Polyethylene was the most common polymer on all beaches (average of 32.3%), followed later by two foamed plastics, polyurethane, and polystyrene (15.3% and 14.9%, respectively); these polymers are commonly used for the manufacture of maritime articles due to the buoyancy they present. In the case of nylon polymer, it was found on four of the five beaches; this type of plastic is widely used in fishing gear.

The most abundant colors were white with an average of 28.0%, followed by yellow with an average of 25.1%. Regarding size, the highest proportions occurred in the range of 4.1 to 5.0 mm (average of 32.0%) and 1.1–2.0 mm with an average of 30.5%.

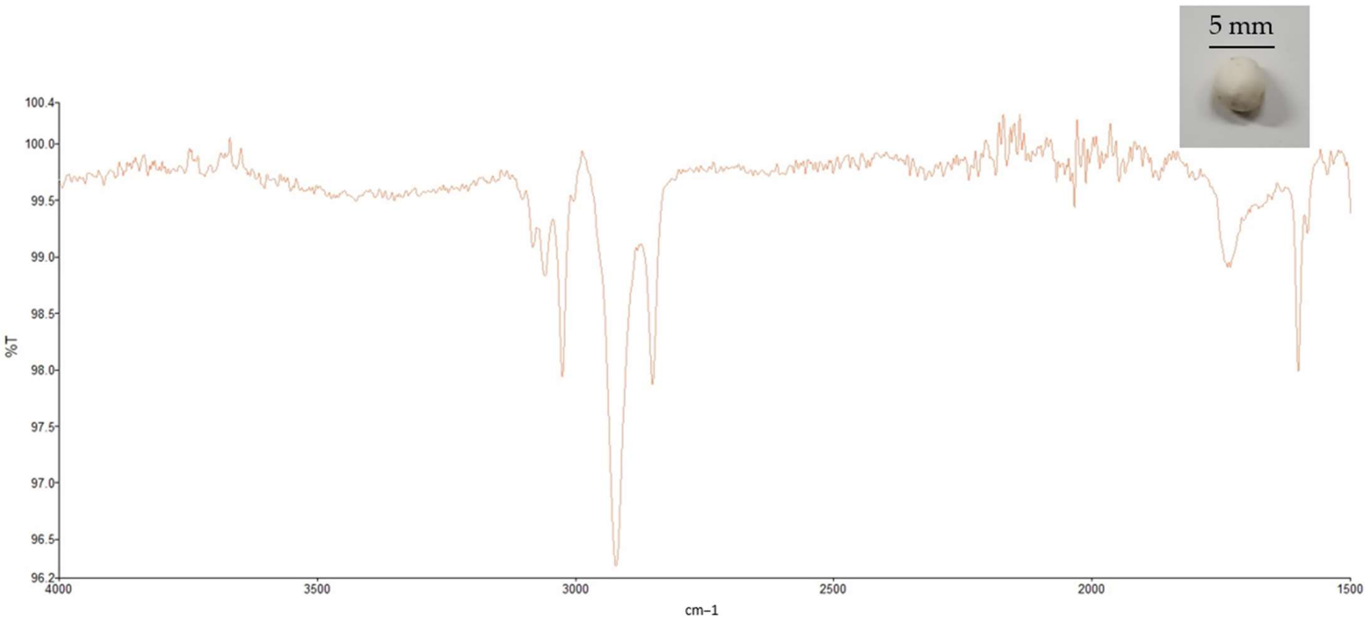
Figure 4 shows examples of the different shapes of MP found in the present study.


**Figure 4.** Examples of shapes of MP: (**a**) spherical, (**b**) foam, (**c**) filaments, (**d**) fragments, and (**e**) films.

On the other hand, Figure 5 shows examples of two spectra of two plastic particles.




(**a**)




(**b**)

**Figure 5.** Examples of spectra: (**a**) PE MP, and (**b**) PS MP.

## 4. Discussion

The Gulf of California region has been affected by anthropogenic activities, which have given rise to different problems directly and indirectly associated with the issue of microplastics. Table 3 presents nine research studies about different contaminants in the Gulf of California, such as phthalates esters (PAEs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals, which can be sorbed in MP [24–26]. The presence of personal protective equipment (PPE) has also been analyzed, which, in the long run, can become MP [25,27]. Finally, MP have been addressed in 70% of the studies presented, in matrices such as bottom sediments, followed by surface water, sand of beaches, and marine fauna.

Concerning MP studies in surface water, this article is the first carried out in the marine region of the Gulf of California, whose concentrations obtained were found in the range of 0.000–0.020 MP/$m^3$. In a study carried out in the Norwest Pacific, by Ramírez-Álvarez et al. [28], MP concentrations in the range of 0.01–0.70 plastic particles/$m^3$ were reported in

Todos Santos Bay, Baja California, while in the studies carried out in Urias estuary Lagoon and Mazatlan Bay by Ríos-Mendoza et al. [29], and La Paz Bay by Galli et al. [30] higher concentrations were obtained (1.7–2 MP/$m^3$ and 0–0.24 MP/$m^3$, respectively) than those of this study.

Regarding the characteristics of the MP, in all the studies in Table 3, including this one, the most common type of MP was fragments. For colors, the most reported was white, while for polymers, these were first PE and second PP. In most of the research that presents the occurrence of microplastics in marine ecosystems, the polymers that appear in the most significant proportions are polyethylene (PE) and polypropylene (PP), and this could be due not only to the fact that they are widely used in the production of plastic products globally but also because their density is lower than that of seawater, so they can float and be transported more easily through surface currents [31–33]. Finally, regarding sizes, only the present study and that of Galli et al. [30] report them, and in both, there is agreement that small MP (0.5–1.0 mm) constituted an important proportion (23% and 27%, respectively).

About the results of the presence of MP on beaches, in terms of mass, it was found that in the study carried out on two beaches in San Felipe in 2018 by Teresita et al. [34], the concentrations were higher (46–283 MP MP/$kg_{dw}$) compared to what was obtained on the beaches of the present investigation (0.9–3.5 MP/$kg_{dw}$). The above is due to the measurement interval in both studies; while in this study, the MPs were detected in the range of 0.5–5 mm, in the 2018 research, it was 0.4 µm to 5 mm.

On the other hand, in a study carried out on Mazatlan City beaches, at the entrance of the Gulf of California, concentrations of 4–36 MP/$m^2$ [29] were reported, which were lower than this study (28.2–200.7 MP/$m^2$), which may be because in the Upper Gulf of California Zone, there is a residual current in the form of a cyclonic gyre [35] that would allow the accumulation of MP instead of displacing them to other areas.

**Table 3.** Relevant information of research studies about pollution in Gulf of California.

| Marine Region | Study Zone and State | Pollutant Type | Environmental Matrix | Relevant Results | References |
|---|---|---|---|---|---|
| Gulf of California | La Paz Bay (Baja California) | MP | Surface water | 68% of the samples contained MP, total of MP: 67, range: 0–0.24 MP/$m^3$. MP characteristics [1]: black and blue, fragments (81%) and fibers (10%), 1–2.5 mm (5%) and 0.5–1 mm (27%), PE (52%) and PP (27%) | [30] |
| | | Phthalates esters (PAEs) | Marine Fauna (Skin biopsies of Whale Shark (*Rhincodon typus*) and Fin whale (*Balaenoptera physalus*)) | PAEs concentration: average of 2007.4 mg/$g_{dw}$ and range of 170–3055 mg/$g_{dw}$ | |
| Gulf of California | Mazatlan coast | MP | 14 beaches | Concentrations: 4–36 MP/$m^2$. MP characteristics [1]: white (48%) and brown (21%), PE (39%) and PP (39%) | [29] |
| | | | Surface water | Concentrations: 1.7–2 MP/$m^3$ (375–397 MP/$m^2$). MP characteristics [1]: fragments, white (54%) and yellow (10%), PP (47%) and PE (45%) | |
| | | | Bottom sediments | Concentrations: 40–782 MP/$m^2$. MP characteristics [1]: white (53%) and black (27%), fibers (75%), PE (21%) and PET (21%) | |

**Table 3.** *Cont.*

| Marine Region | Study Zone and State | Pollutant Type | Environmental Matrix | Relevant Results | References |
|---|---|---|---|---|---|
| Gulf of California | Santa Maria La Reforma Estuarine System (Sinaloa) | MP | Bottom sediments | Total: 104 MP (3.58 MP/kg). MP characteristics [1]: transparent (39.3%) and blue (38.3%), fibers (100%), nylon polyamide (49.3%) and PE (38.5%) | [36] |
| | | | Marine fauna (Gastrointestinal tract (stomach) of Haller's Round Ray, (*Urobatis halleri*)) | Total: 386 MP. MP characteristics [1]: blue (61.5%) and black (17.6%), fibers (98.7%) and fragments (0.5%), nylon polyamide (45.3%) and PET (30.2%) | |
| Gulf of California | Espiritu Santo Island and Cabo Pulmo (Baja California) | MP | Coral Reef Bed Sediments | Concentrations: Espiritu Santo Island 321.75 MP/100 $g_{dw}$, Cabo Pulmo: 680.25 MP/100 $g_{dw}$. MP characteristics [1]: white (55%) and transparent (25%), fibers (75%) and fragments (19%), 1672 μm (average size), PE (70%) and PET (65%) | [37] |
| Gulf of California | Urias Estuary Lagoon System (Sinaloa) | MP | Bottom Sediments | Concentrations range: 0–2.247 ± 71 MP/kg. MP characteristics [1]: blue (11–65%) and white (3–47%) only for fibers, fibers (85%) and fragments (37%), PET (14–50%) and PE (17–30%) | [31] |
| Gulf of California | Sonora coast | Personal Protective Equipment (PPE) | 3 beaches | Masks: 201 pieces (96%), hand sanitizer wipes: 7 pieces (3%), gloves: 2 pieces (1%). Overall average PPE density in 2021 was $1.80 \times 10^{-4} \pm 1.19 \times 10^{-4}$ PPE/$m^2$ (0–$3.77 \times 10^{-4}$ EPP/$m^2$) and for 2022 it was $7.84 \times 10^{-5} \pm 8.79 \times 10^{-5}$ PPE/$m^2$ (0–$2.96 \times 10^{-4}$ PPE/$m^2$). Masks colors: blue (50%), black (37.6%), white (9.9%), others (2.5%) | [38] |
| Gulf of California | La Paz Bay (Baja California) | Polycyclic Aromatic Hydrocarbons (PAHs) | Marine fauna (Soft tissue of Mussels (*Modiolus capax*)) | Concentrations: 147.01–271.09 mg/$g_{dw}$ | [39] |
| | | | Bottom Sediments | Concentrations: 18.9–94.5 mg/$g_{dw}$ | |
| Gulf of California | Southeastern Gulf of California (Sinaloa) | Heavy Metals | Surface Water | Zn (3.06 ± 2.64 μ/L), Cu (1.90 ± 1.58 μ/L), Mn (1.87 ± 0.47 μ/L), Cd (0.11 ± 0.06 μ/L), Pb (0.09 ± 0.05 μ/L) | [40] |
| | | | Bottom Sediments | Mn (49 ± 20 μ/g), Zn (23,7 ± 19 μ/g), Cu (10.8 ± 1.8 μ/g), Pb (2.79 ± 3 μ/g), Cd (0.22 ± 0.9 μ/g) | |
| Pacific Northwest and Gulf of California | Baja California Peninsula | MP | 21 beaches | Concentrations: average 135 ± 92 particles/$kg_{dw}$ and range 16 ± 4 to 312 ± 145 particles/$kg_{dw}$. MP characteristics [1]: black (59%) and blue (25%), fibers (91%) and films (5%), size of 0.1–6.5 mm | [34] |
| Gulf of California | Baja California and Baja California Sur | MP | 5 beaches | Concentrations: 28.2–200.7 MP/$m^2$ (0.9–3.5 MP/$kg_{dw}$). MP characteristics [1]: fibers (33%) and fragments (32%), PE (32%) and PU (15%), white (28%) and yellow (25%), 1.1–2.0 mm (31%) and 4.1–5.0 mm (32%) | This study |
| | | | Surface water | Concentrations: 0.000–0.020 MP/$m^3$. MP characteristics [1]: fragments (69%) and fibers (32%), PE (60%) and nylon (20%), blue (38.5%) and white (15.4%) and 2.1–3.0 mm (31%), 0.5–1.0 mm and 3.1–4.0 mm (23% each one) | |

[1] Only the two categories with the highest percentages are reported for the color, shape, size, and polymer of MP. dw = dry weight, PE = polyethylene, PP = polypropylene, PET = polyethylene terephthalate, PU = polyurethane, Zn = zinc, Cu = copper, Mn = manganese, Cd = cadmium, Pb = lead.

The sources by which plastic and microplastic waste could reach the Gulf of California area are mainly: anthropogenic human activities carried out on land, population growth, tourist activities, fishing, proximity from ports, wastewater discharge, runoff caused by rain, winds, and sea currents [29–31,37]. The latter plays a fundamental role in the distribution of plastics that are floating on the surface water. The entrance to the Gulf of California (triangular area located between Cape San Lucas, Mazatlán, and Cape Corrientes) is comprised of a very complicated thermohaline structure characterized by fronts, eddies, and intrusions that may be linked to the convergence of three different currents [41].

Within the Gulf of California, there are different areas that could present different hydrodynamic characteristics that influence the distribution and accumulation of plastic waste, examples of this are Cabo Pulmo, the Bay of La Paz, and the Guaymas basin. The transport of MP can be favored by the tides and the coastal dynamic process, as is the case of Cabo Pulmo, which is located in an open mouth area between the Gulf of California and the Eastern Pacific Ocean and is also affected by the cyclonic and anticyclonic eddies that form in the summer due to the currents of the Gulf of California that come from the northern region [37,42]. The opposite case is the Bay of La Paz, which is located in a semi-closed area in which the circular current would show a distribution pattern of plastic waste different from that of Cabo Pulmo [37].

Regarding the Guaymas Basin, since it is in the center of the Gulf of California, there is a dynamic activity of marine currents that propel the materials that are floating [43], especially those coming from anthropogenic activities that takes place in the port of Mazatlán or in nearby ports [37]. Additionally, the distribution of plastic waste through the marine currents of the Gulf of California is also affected by seasonal variation, since in the spring there is the presence of the South Equatorial current and in the fall of the Costa Rica currents [37,44].

The Gulf of California has the most significant productivity and biological diversity worldwide, as it is home to mammals, fish, and birds, native to the region. MPs can also interfere with the food chain; Zooplankton occupies the primary level in the pyramid and is the leading consumer of plastic particles in high concentrations, which represents a risk for organisms at higher trophic levels, such as crustaceans, fish, and birds, which can also accumulate MP in various organs and tissues [4].

According to Merrill et al. [10], marine mammals could be especially predisposed to MP accumulation due to their feeding behaviors and anatomy, such as the Vaquita Marina. The thick layer of vascularized subcutaneous adipose tissue is a fundamental energy reservoir in marine mammals, characteristics that make it prone to the accumulation of MPs transported by the circulatory system. The acoustic organs of odontocetes can also be important accumulation sites due to the fat and blood vessels that make them up.

Several studies in the literature show the presence of MPs in the digestive systems of odontocetes such as common dolphins (*Delphinus delphis*), striped dolphins *(Stenella coeroleoalba)*, bottlenose dolphins (*Tursiops truncatus*), Risso's dolphin (*Grampus griseus*), pygmy sperm whale, and typical harbor porpoises [9,45,46]. On the other hand, MP translocation has been little studied in marine mammals; however, Merrill et al. [10] demonstrated the existence of plastic particles in acoustic fat pads, adipose tissue, lungs, and melon of mystecete, odontocete, and phocid species. The effects of MP on this type of organisms still require further research.

Considering the above, the physical and toxicological risks to which vaquitas are exposed due to the presence of MP, pose other potentially important obstacles in the conservation of these species.

## 5. Conclusions

This research showed the presence of microplastics in the surface water of the Vaquita refuge area (0.000–0.020 MP/m$^3$) and on sandy beaches (28.2–200.7 MP/m$^2$) surrounding this area. The surface water transects (Transects I-J and J-27) and the beaches (Hawaii and San Felipe beaches) with the highest concentrations of microplastics are located near the port of San Felipe, which indicates that the microplastics present there could come from the urban zone. The above is because San Felipe is the most populated municipality in the region with nearly 17,000 inhabitants, and it is also a port with intense fishing activity, which could generate microplastics from the fishing gear used, lost, or abandoned.

The presence of MP in the Vaquita Marina polygon and the surrounding beaches means a pollution problem that can increase if the intensity of fishing activity and population growth in the area increases. The latter is related to the discharge of wastewater and the generation of solid waste, which also has implications for the formation of microplastics. MP represents a risk to the biota due to their size; their removal is impossible, and different marine species could ingest them, causing different effects. In the case of the Vaquita Marina, it could be predisposed to the accumulation of MP in the layer of vascularized subcutaneous adipose tissue, in the acoustic organs, and the digestive systems; however, the effects of MPs in this type of organism (mammals odontocetes) still require further research.

In this study, the presence of MP was only considered in specific transects of the Vaquita Marina polygon, not in all, as well as in some beaches that surround it; therefore, it is recommended to study all the transects that make up the polygon, as well as a more significant number of beaches and in different seasons. In addition, biopsy skin samples could also be considered in the Vaquita Marinas to evaluate the presence of chemical compounds that could be desorbed by the MPs in the surrounding water. These studies will help better understand pollution patterns in water, beaches, and biota and establish measures to reduce or prevent its presence.

**Author Contributions:** Conceptualization, J.C.A.-Z., A.A.C.-S. and A.V.-M.; methodology, J.C.A.-Z. and A.A.C.-S.; formal analysis, S.O.-B. and S.E.C.-S.; investigation, J.C.A.-Z., J.T.-F., S.L.D.L.-R. and A.A.C.-S.; resources, S.O.-B., A.V.-M. and J.C.A.-Z.; data curation, S.E.C.-S.; writing—original draft preparation, J.C.A.-Z., J.T.-F., S.L.D.L.-R. and A.A.C.-S.; writing—review and editing, A.V.-M., S.E.C.-S. and S.O.-B.; project administration, A.V.-M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was partially funded by the National Council of Science and Technology of Mexico (CONACYT), through PhD scholarships with CVU numbers 839723 and 438727, provided to the first and second authors.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data are contained within the article.

**Acknowledgments:** The authors thank the Secretaria de Medio Ambiente y Recursos Naturales and Secretaria de Marina for the support provided in carrying out this research.

**Conflicts of Interest:** The authors declare no conflict of interest.

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