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Microplastic in Commercial Fish in the Mediterranean Sea, the Red Sea and the Arabian/Persian Gulf. Part 3. The Arabian/Persian Gulf

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Abstract

The manuscript reviews the available literature of 2015-2022 on the microplastic content in commercially important fish species, molluscs and crustaceans in the Arabian/Persian Gulf. The literature on microplastic concentrations on beaches, in subtidal sediment, and in surface water of different regions of the Arabian/Persian Gulf is evaluated, also. Overall, the reported concentration of microplastic in marine organisms in the Gulf has been found to be less than for comparable waters such as the Mediterranean Sea. The highest microplastic concentration within the region of the Gulf has been found on its Northern shore, in Iran, where also most of the microplastic studies within the region stem from.

Keywords

Review, Commercial Fish, Arabian/Persian Gulf, Microplastic, Environmental Pollution

1. Introduction

Microplastic (MP), small plastic particles of less than 5 mm in size [1], is seen as an emerging pollutant that has infiltrated the marine ecosystem, where MP not only can be found throughout the water column [2], in surface water [2] [3], making up a part of the 5 trillion plastic pieces floating on the oceans' surface [4], in marine sediments [5] [6] and on beaches [7] [8], but also at every trophic level [9] [10]. In 2015, it was estimated that 93.000 - 236.000 metric tons of MP can be found in the world's oceans [11]. An estimate from 2018 increased the amount to 270.000 tons [12]. The sources of MP in the marine environment are diverse. Some of them are land-based—thus it is assumed that up to 5% of the plastic waste generated on land ultimately makes its way into the oceans. Others stem from human activities on the water, where 10% of large plastic input derives from the fishing industry in form of nets and other fishing gear [13]. Shipping contributes to plastic and therefore MP waste, also, where gray water from the ships [14] as well as protective ship coatings [15] can carry large amounts of MP into the marine environment. Transport of MP from land to water happens both through water as well as through airborne transport [16]. In the first case, untreated run-offs [17] [18] and to a lesser degree effluents from wastewater treatment plants contain MP [19].

Marine organisms take up MPs. This includes marine phyla of commercial value such as marine vertebrates (such as cetaceans and fish), molluscs (gastropods, cephalopods and bivalves), and arthropods (crustaceans). Seafood in markets has been shown to be contaminated with MP [20] [21] [22]. As usually MP contamination is restricted to the intestinal tract of the organism, bivalves and fish eaten whole are more likely to expose humans to MPs [23]. The fact is that MPs have been found in human feces [24] [25], blood [26] and also in human placenta [27] [28] and meconium [28]. While many polymers that make up MPs are chemically inert, MPs can impart physical damage to tissues [29] and specifically to cells [30]. In addition, MPs contain additives such as plasticizers, flame retardants, stabilizers and dyes, which may have a detrimental effect on living organisms [31] [32], including humans [33]. Thus, phthalates used as plasticizers have been listed as potential endocrine disruptors [34] and as potentially carcinogenic materials [35]. Furthermore, MPs can adsorb small organic compounds [36] such as polycyclic aromatic hydrocarbons (PAHs) [37] and polychlorinated biphenyls (PCBs) [38], heavy metals [39] as well as microorganisms [40]. Then, MPs can serve as vehicles for such toxic assemblages [41] [42] [43] [44].

Apart from the Atlantic Ocean off the coast of Morocco and Mauritania and the Arabian Sea, the Mediterranean Sea, the Arabian/Persian Gulf and the Red Sea are the most important larger water bodies for the MENA region. The Mediterranean Sea, the Arabian/Persian Gulf and the Red Sea are semi-enclosed and are situated in a relatively arid region. The Arabian/Persian Gulf is bounded by the Shatt al-Arab river delta in the northwest and by the Strait of Hormuz in the southeast and is bordered by the countries of Iran, Iraq, Kuwait, Saudi Arabia, Bahrain, Qatar, the United Arab Emirates (UAE), and Oman. Large cities such as Dubai (UAE, 2.9 million inhabitants), Abu Dhabi (UAE, 1.51 million inhabitants), Doha (Qatar, 2.38 million inhabitants), Manama (Bahrain, 436.000 inhabitants), Dammam (Saudi Arabia, 1.25 million inhabitants, Metro area Dammam-Khobar: 4.14 million inhabitants), Kuwait City (Kuwait, 3 million inhabitants) and Bandar Abbas (Iran, 527.000 inhabitants) circle the Gulf. In 2020, daily, 18 million barrels of oil passed through the Strait of Hormuz. 7.3% of global plastic materials production is situated in the Middle East [45]. At the same time, the countries surrounding the Gulf produce in excess of 5.81 million tons of plastic waste per year (Al Salem *et al*., 2020), with Saudi Arabia (1.92 million t/a), the United Arab Emirates (1.29 million t/a) and Iran (1.96 million t/a) producing the largest share. At the consumer level in the UAE, this translates into an average annual use of 450 plastic bottles and of 1100 plastic bags per person [46], only 10% of which are currently recycled. In Abu Dhabi, it also translates into an average daily municipal solid waste generation of 1.56 kg per person [47].

The Arabian/Persian Gulf provides important fishing grounds. Fish catches in the Arabian Gulf have averaged 331,827 tons annually (2004-2012), with a minimum of 208,520 tons in 2004, and a maximum of 421,606 tons in 2012 [48]. According to Al-Abdulrazzak *et al*. [49], over the time period 1950-2010, the dominant invertebrate groups in the catches are shrimps and prawns (7%), and crabs and lobsters (6%), with the major fish groups consisting of herring-like fishes Clupeiformes (10%), sharks and rays (8%), ponyfishes (6%), and catfishes (6%), with another > 10% of annual landings being composed of species belonging to the families Carangidae, Lethrinidae, and Serranidae [50] [51]. In recent years, however, all countries on the Arabian/Persian Gulf have developed fish farming as a major food industry, as the natural fish stocks in the Gulf had been over-exploited for years. In this way, Qatar was able to produce 15,087 tons of fish in 2020, leading to the 66.7% self-sufficiency in fresh fish.

While traditionally there has always been a worry in regard to contamination in fish, be it because of heavy metal contamination [52] [53] or because of persistent organic pollutants [54], the presence of MP in fish has added a new concern. The current contribution, the last of three reviews of MP presence in the water bodies of the MENA region [55] [56] assesses the occurrence of MP in commercially valuable fish and other marine species in the Arabian/Persian Gulf in view of published literature from 2015-2022. Earlier sporadic reports on plastic micropellets, eg., spilled primary microplastics, beaches in Kuwait [57] and in the United Arab Emirates [58] [59] have not been included.

2. Data Collection

For this review, the authors have used the databases Scopus®, Scifinder® and Web of Science®. Typical keyword combinations used were “Arabian Gulf AND microplastic”, “Persian Gulf AND microplastic”, “Arabian Gulf AND microplastic AND fish”, “Persian Gulf AND microplastic AND fish”, “country AND microplastic, with country = Iran, Iraq, Kuwait, Bahrain, Saudi Arabia, Qatar, United Arab Emirates (Dubai) and Oman” to give as an example 11 entries (Arabian Gulf AND microplastic), 25 entries (for Persian Gulf AND microplastic), 2 entries (for Arabian Gulf AND microplastic AND fish), 10 entries (Persian Gulf AND microplastic AND fish), 82 entries (for Iran), 1 entry (Iraq), 13 entries (Kuwait), 1 entry (Bahrain), 37 entries (Saudi Arabia), 9 entries (Qatar), 3 entries (United Arab Emirates), 2 entries (Dubai), 7 entries (Oman) respectively, in Web of Science® and 10 entries (Arabian Gulf AND microplastic), 29 entries (for Persian Gulf AND microplastic), 4 entries (for Arabian Gulf AND microplastic AND fish), 10 entries (Persian Gulf AND microplastic AND fish), 45 entries (for Iran), 3 entries (Iraq), 5 entries (Kuwait), 1 entry (Bahrain), 12 entries (Saudi Arabia), 6 entries (Qatar), 1 entry (United Arab Emirates), 1 entry (Dubai), 5 entries (Oman) in SciFinder®. Publications by governmental organizations, intergovernmental organizations (IGO's) and or nongovernmental organizations (NGO's), which are often not abstracted by the above databases, were searched for on the world-wide-web, utilizing the search words above. Abstracts of all entries were screened. When the abstract indicated that a quantitative analysis of microplastic in the region of the Arabian/Persian Gulf was presented, the paper was obtained through the UAEU university library system. All pertinent references in the given papers were screened for any missed publications. The "forward" citations given in the databases for the entries found in the databases were also screened for any missed publications. Papers were included in this review with detail quantitative analyses of microplastic in fish, water, beaches/coasts and sediments within the region of the Arabian/Persian Gulf. No review was discarded on the basis of the actual data presented. Where data seemed to be in conflict with other published data, the conflict was stated in the review without evaluation of the actual data. To decide upon the commercial values of different marine organisms, capture production statistics from FAO Fisheries & Aquaculture were used. There have been five reviews that touch upon certain aspects of the current contribution [60] [61] [62] [63] [64].

It must be noted that the majority of the work on MP in the Arabian/Persian Gulf comes from Iran and encompasses sampling of the Northern shore of the Gulf. In frequency of publications, this is followed by work from Kuwait with sampling of Kuwaiti waters in addition to collaborative research with Iran. Less work can be found that is focused on Qatari sites and sites in Saudi Arabia and the United Arab Emirates. No published work has yet appeared on Bahraini waters and beaches. Work from Oman has focused on sites along the Gulf of Oman and was exempted from this review.

3. Abundance of Microplastic in the Arabian/Persian Gulf

The last decades saw significant changes along the coasts of the Arabian/Persian Gulf, affected by an ever-increasing population, a changing economy and newly-found wealth on the back of hydrocarbon extraction. Between 1960 and 2021, the population of United Arab Emirates grew from 92.500 to 9.89 million people, that of Qatar from 47.400 to 2.88 million people, and that of Kuwait from 269.000 to 4.27 million people. This has led to significant coastal developments [65] [66] that include the construction of artificial islands and an increased urbanization of coastal stretches. This has resulted in the introduction of

MP from land into the Gulf, through direct airborne transport [67], due to direct anthropogenic activity near or on the Gulf, through the discharge of wastewater treatment plants [68] and through run-offs [69]. Studies from the Iranian coast have shown that as much as 1.2 × 108 MP per day could be released into the Persian Gulf from Bandar Abbas city alone [68]. So, it is not surprising that among the beach locations studied by Naji *et al.* in 2017, the location with the largest concentration of MP was near an industrial wastewater output. Nevertheless, many of the MPs found in the marine environment are secondary MPs stemming from macroplastics through photodegradation in the environment and through degradation by the combined effects of wave action and abrasion from sediment particles [70] [71]. This is especially true in the Arabian/Persian Gulf, with its high salinity and high temperatures. Furthermore, Naji *et al.* [72] [73] attributed many MPs found on beaches or in intertidal zones to tourism and recreational activities, something which Sarafraz *et al.* [74] had voiced earlier. Thus, the authors found significant amounts of plastic debris at the touristic beaches Khor-e-Yekshabeh and Bostanu, Hormozgan Province, but not within the marine protected area at Khor-e-Azin. This was also reflected in the number of MP found at different sites: 2 ± 1 MP/kg (dry sediment) at Khor-e-Azin versus 1258 ± 291 MP/kg at Bostanu, the most industrial site of the beach sites sampled by the authors along the Strait of Hormuz [72] [73]. Akhbarizadeh *et al.* studied the MP concentration at 11 different stations around Khark Island, a hub for Iranian oil storage and shipment located in the Northwestern part of the Gulf. Again, while MPs were found in all collected sediment samples, significant higher MP concentrations of up to 217 ± 20 items/200g dry sediment were found near human settlements and anthropogenic activity, including near petrochemical operations, as compared to more secluded locations with a MP count of 59 ± 20 items/200g dry sediment. On the beaches of Karkh Island, the majority of the identified MPs were fragments (61.7%) and fibers (37.2%) of <100 μm in size [75]. Also, Dobaradaran *et al.* [76] observed appreciable MP concentration on 9 urban beaches around Bushehr City with more than 2.2 × 104 MP/m^2 within the top 10 cm of the beach layer at Jofre, Bushehr. Abayomi *et al.* sampled the intertidal zones of 8 Qatari beaches, evenly distributed along the Qatari coastline. The observed MP counts were between 36 and 228 MP·m^{-2} or between 6 and 38 MP·kg^{-1} of dry sediment. MP consisted of fibers (43/8%), films (40.7%) and fragments (14/2%) [70]. Frequent beach cleaning may offset heavy usage of the beaches, however, no direct relationship was found between the concentration of macroplastic and microplastic particles on the Qatari beaches. Abayomi reasoned that it is likely that MP found in the intertidal zones originate as much from the sea as from a local fragmentation of beach litter [70]. In this respect, S.Veerasingam *et al.* [77] noted that the density of macrolitter (ML) on the west coast of Qatar is with 1.98 items/m^2 higher than the global average, with PET bottles, and fishing gear debris in high abundance. Most plastic macroparticles discovered on beaches in the northwest part of Qatar were highly weathered and associated with barnacles and growth of cyanobacteria, fungi and algae, with especially plastic macrolitter (ML) on islands off the Northwest coast being covered with assemblages of encrusting organisms, indicating long residence time at sea. The authors also investigated the country of origin of ML deposited on the western beaches of Qatar and found that 45.3% of the items seemed to be land originated, 8.75% sea-originated, while 20.4% of the ML items originated from neighboring countries and the origin of 25.4% of ML items could not be identified. Veerasingam *et al.* [78] looked at the vertical penetration of MP particles in beach sediments and have found that on average over 9 locations, the MP concentration decreased from 320.7 ± 234 particles/kg in the top 5 cm sediment to 49.1 ± 17 particles/kg at 5 - 10 cm depth, 12.7 ± 9 particles/kg at 10 - 15 cm depth and 1 ± 3 particles/kg at 15 - 20 cm depth, with no MP found at depths of more than 20 cm. Kuwaiti beach sediments were surprisingly devoid of MP contamination. T. Saeed reported only 37 MP altogether from 44 intertidal locations along and to the south of Kuwait Bay [79]. Beaches in the area stretching from Ras Al-Ard to Shuwaikh port were reported completely free of MP. A few MPs were found in the samples from the beaches extending west from Shuwaikh to Jahra. The authors explained the very low concentration of MPs on Kuwaiti beaches with the fact that all of them are serviced in further south, in the United Arab Emirates. H. Aslam *et al.* [80] found an average of 59.7 MP/kg of dry sediment equaling 165 MP/m^2 when sampling 16 Dubai beaches, with a range of 337 ± 180 MP/m^2 (133.98 ± 67.48 MP/kg sediment) to 26 ± 5 MP/m^2 (8.43 ± 1.54 MP/kg sediment). Some of the beaches are at least semi-serviced.

Thus, MP quantification in sediments along the coastline of the Arabian/Persian Gulf has been carried out in a number of locations (**Figure 1**). Starting with the Northwestern coastline and then turning clockwise, the following are some of the values that have been published, given either as number of MP per kg of dry sediment or number of MP per m^2 surface with a defined thickness of layer analyzed: Iran (Hormozgan Province): Khor-e-Yekshabeh (125 ± 25 particles/kg dry sediment), Gorsozan (103 ± 12.6 particles/kg), Khor-e-Azini (42.7 ± 5.5 particles/kg), Bostanu (36.0 ± 7.2 particles/kg), Suru (n.d) [72] [73], Khor-e-Yekshabeh, Bandar Abbas (3.36 × 10^4 particles/m^2), Gorsozan, Bandar Abbas (3.54 × 103 particles/m^2), Suru, Bandar Abbas (1.65 × 104 particles/m^2) [81], Lashtaghan (26.5 ± 6.36), Gelkan 19.5 ± 6.36) [82], Iran (Bushehr Province): Nayband National Marine Park), Nakhilo Island, and Bardestan: Bidkhoun (2 locations: 416 particles/m^2 [urban]; 280 partcles/m^2 [industrial]; Hale-Basatin (56 particles/m^2), Bardestan (44 particles/m^2), Bordekhan (14 particles/m^2) [83]; Qatar: Ras Rakan Island (9 locations: 320.7 ± 234 particles/kg) [78]; Umm Bab (52.1 particles/m^2); Dukhan (84.1 particles/m^2); Al Ruwais (47.9 particles/m^2); Ras Laffan (84.5 particles/m^2); Al Dakhira (76.1 particles/m^2); Pearl Beach (123.9 particles/m^2); Doha Beach (123.9 particles/m^2); Mesaieed (56.2 particles/m^2) [70]; United Arab Emirates (Dubai): Al Mamzar Beach Park, Dubai (3 locations: 245 ± 106; 152 ± 63; 84 ± 21 particles/m^2), LaMer Beach, Dubai (2 locations: 226 ± 73; 337 ± 180 particles/m^2); Mercato Beach, Dubai (121 ± 8 particles/m^2), Jumeriah Open Beach, Dubai (170 ± 57 particles/m^2);

Sufouh Beach, Dubai (176 ± 61 particles/m^2); Marina Beach, Dubai (119 ± 26 particles/m^2) [80].

Measurements of the MP concentration in the water at different locations within the Arabian/Persian Gulf have been published, also (**Figure 1**). Again, much of the data comes from Iran. In 2020, Kor and Mehdinia collected neustonic samples from 15 stations along the Iranian coast, from the Strait of Hormuz to off the coast of Abadan, Khuzestan Province, with the sampling points being at varying distances of 7 - 90 km from the shoreline [84]. The average MP concentration was found to be 1.8 (±1.1) × 10^4 particles/km^2 where the sampling point closest to the shore (9 km off Dehr, Bushehr Province) showed the highest MP concentration with a density of 4.6 × 10^4 particles/km^2. Interestingly, the lowest MP concentration was measured just beyond the Strait of Hormuz in the Gulf of Oman with 1.5 × 10^3 particles/km^2. With two notable exceptions, namely at locations off the Parsian county coastline and in the Strait of Hormuz, where mostly plastic fragments were observed, the majority of particles found were fibers [84]. MP concentrations in Kuwaiti water, both in and to the south of Kuwait Bay, in the area stretching from Ras Al-Ard to Shuwaikh port, and in the South of Kuwait Bay, have been found to be extremely low, as reported by Saeed *et al.* in 2020. In 40 neuston net trawls of 1 km length each, only 12 MP were found altogether [79]. In 2014-2015, Abayomi *et al.* [70] found MP concentrations of between 4.38 × 10^4 and 1.46 × 10^6 particles·km^{-2} in the surface water off the eastern coast of Qatar, with the highest concentration observed at 10 km off the coast. With 93.8%, fibers were the dominant type of MP. 67.4% of the found MP were 1 - 5 mm in size [70]. Castillo *et al.* [85] sampled surface water at 12 marine stations in the Northeast of Qatar in the Qatari EEZ at up to 95 km from the coastline with a maximum MP concentration of 3 particles/m^3 seawater. It must be noted that two sites, namely one in the Doha channel about 16 km off the coast and the site furthest out returned samples with no MP content.

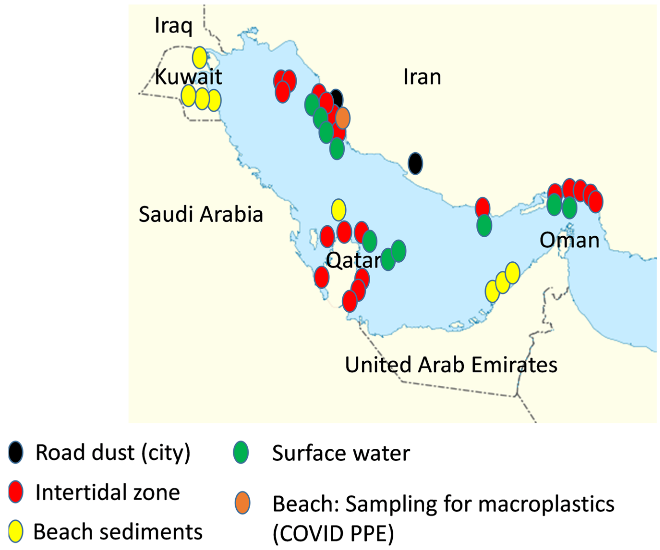

Figure 1. MP sampling sites—on land, beaches, intertidal zones and surface waters.

Many of the sampling stations, including those near Halul Island were in the vicinity of Qatari offshore oil fields.

4. Microplastic Abundance in Fish, Crustuceans, and Molluscs in the Arabian/Persian Gulf

4.1. Status of Commercial Fish Stocks in the Arabian/Persian Gulf

A wealth of data is available on the recent development of fishery stocks in Kuwaiti waters [86]. Eight important species of fish have decreased in stock over recent years—these are *Pampus argenteus* (silver pomfret, Zobaidi), *Tenualosa ilisha* (Hilsa shad, Suboor), *Pomadasys kaakan* (javelin grunter, Nagroor), *Epinephelus coioides* (orange-spotted grouper, Hamoor), *Lutjanus malabaricus* (Malabar blood snapper, Hamra), *Parastromateus niger* (black pomfret, Halwayuh), *Plectorhinchus pictus* (trout sweetlips, Frush), and *Saurida tumbil* (greater lizard fish, Kasur). Part of this is due to overfishing, part of it is due to environmental pollution [87]. Overall, the fisheries production in Kuwait has declined by about 25% since the late 1980s [88]. Furthermore, the shrimping industry in Kuwaiti waters is very important, with the two main shrimp species *Penaeus semisulcatus* (green tiger prawn) and *Metapenaeus affinis* (jinga shrimp). Shrimping industry is important for Iran and Saudi Arabia fisheries [49], too, where in Iran also *Penaeus merguiensis* (banana prawn), *Metapenaeus stebbingi* (peregrine shrimp), *Parapenaeopsis stylifera* (Kiddi shrimp) and *Metapenaeopsis stridulans* (Fiddler shrimp) are caught [89]. Nine species of fish were highlighted by the United Arab Emirates Ministry of Climate Change and the Environment (MOCCAE) to be of commercial value: *Lethrinus nebulosus* (spangled emperor, Shaari), *E. coioides* (orange-spotted grouper, Hamour), *Siganus canaliculatus* (white-spotted spinefish, Safi arabi), *Acanthopargus bifasciatus* (twobar seabream, Faskr), *Rhabdosargus sarba* (goldlined seabream, Qabit), *Gerres longirostris* (strongspine sliver biddy, Badah), *Scombroides commersonianus* (Talang queenfish, Dala), *Cephalopholis miniata* (coral grouper, Arousa), and *Thunnus tonggol* (longtail tuna, Gebab) [90]. Groupers (*Epinephelus* spp.), emperors (*Lethrinus* spp.) and mackerels (*Scomberomorus* spp.) were historically the commercially most important for Qatari fisheries, with the emperor fish making up 50% of the revenue for the Qatar National Fishing Company (QNFC) in previous times [91]. Sardine, mackerel, tuna, barracuda, grouper, trevally, emperor, and pomfret along with shrimps still make up the majority of the seafood market in Qatar. In Bahrain, rabbit fish (Safee) (*Siganus canaliculatus*), Sobaity bream (silver seabream, Sobaity) (*Sparidentex hasta*), orange-spotted grouper (Hamoor) (*E. coioides*), gilthead seabream (*Sparus aurata*), mangrove snapper (Sheggar) (*Lutjanus argentimaculatus*), and cobia (*Rachycentron canadum*) are seen as commercially important local species, and these are all species cultured in Bahrain [92]. In general it can be said that In the wild, many of the commercial species in the Arabian Gulf suffer from overfishing. In all the above countries many of the fish are farmed, where the countries on the Arabian Peninsula coast of the Gulf are preparing to have some of the largest salt water aquaculture set-ups in the world. One needs, however, to note that microplastic has also been found in farmed fish throughout the world [93] [94].

4.2. MP Status in Molluscs and Crustaceans in the Arabian/Persian Gulf

Let us look at some of the work done on determining MP content in fish and molluscs caught in the Arabian/Persian Gulf (**Figure 2**, **Figure 3**, **Table 1**). At this time, results stem mainly from Iran, Kuwait, and Saudi Arabia, with again the majority of the data coming from Iran, published in the years 2018-2020. Naji *et al.* (2018) investigated the MP contamination in five different molluscs (*Pinctada radiata*, *Thais mutabilis*, *Cerithidea cingulata*, *Amiantis umbonella* and *Amiantis purpuratus*) [95]. Two of the three sampling sites for the molluscs were in Khor-e-Khoran, to the east of Bandar Abbas, which contains extensive mangrove forests and has the status of Hara (mangrove) protected area (HPA) with commercial use restricted to fishing, tourist boat trips, and limited mangrove cutting for animal feed [95]. The molluscs were collected in the intertidal zone during low tide. In individuals of all 5 species MPs were detected, where the average number of MPs found in the animals ranged from 0.2 to 21.0 particles per g of soft tissue (wet weight) and from 3.7 to 17.7 particles per individual. The results from Naji *et al.* may indicate a trophic transfer of MPs as the MP count in predatory species, especially in the carnivorous snail *T. mutabilis* was found to be higher than in either deposit/ suspension feeding snails (C. cingulate) or clams (*A. umbonella* and *A. purpuratus*) [95]. Biomagnification through trophic transfer is not always seen, however, and Ahmadi *et al.* observed that in certain scenarios marine species at lower trophic levels can even be at greater risk of MP contamination than species at higher trophic levels [[96], see also ref. [102]]. An average MP abundance of 1.02 items/g was found in the digestive tissues

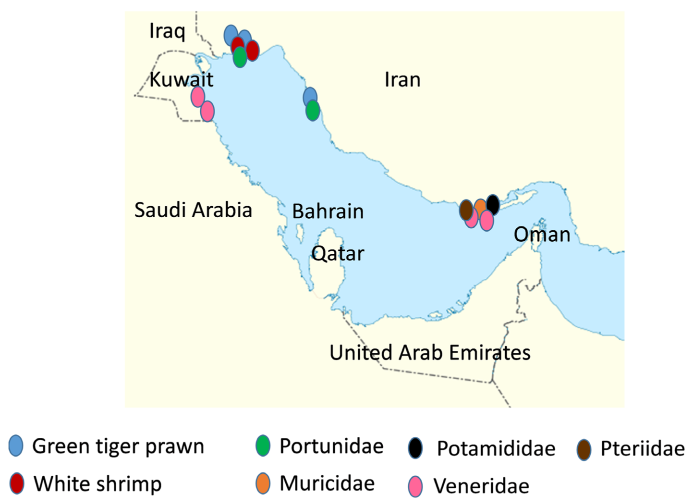

Figure 2. Sampling sites—MP determination in crustaceans and molluscs.

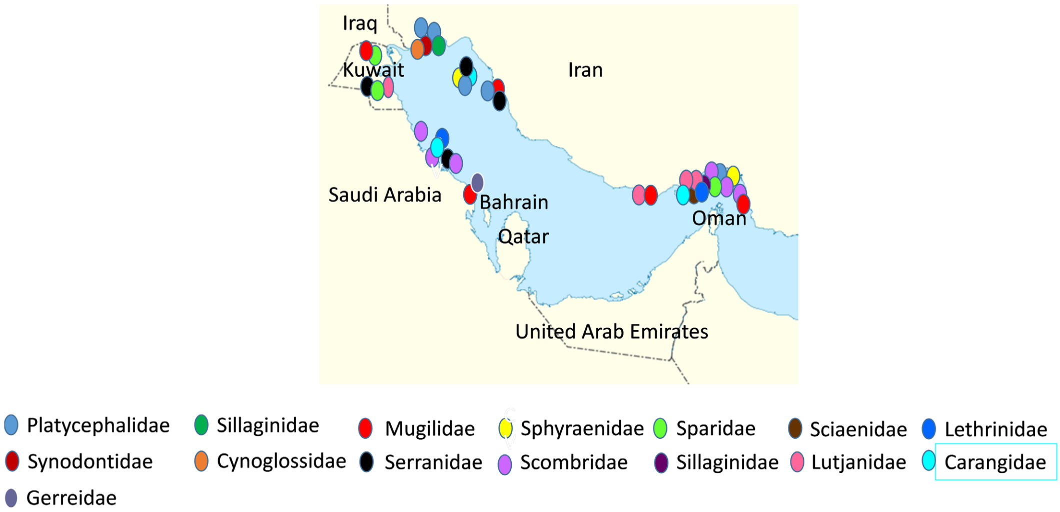

Figure 3. Sampling sites—MP determination in fish of commercial value.

of the white shrimp (jinga shrimp, *Metapenaeus affinis*), sampled from 13 stations along Musa bay, a region of high anthropogenic pressure. The authors commented that on the basis of human consumption data of the white shrimp, an average person could consume 857 MPs per year, deriving from this food source alone [97]. Also, the bivalves hooded oyster (*Saccostrea cucullata*), *Circenita callipyga*, *Barbatia helblingii*, *Solen brevis*, *A. umbonella*, and the gastropod mollusc *Telescopium telescopium* from the coastal area of Hormogzan Province, Iran, were scrutinized for MPs [98].

Mangroves are thought to be MP sinks [99] [100]. In this respect, Maghsodian *et al.* determined the plastic content in sediments in mangrove forests of Nayband Gulf, Bushehr Province, Iran and found 2169 MP for every 349 mesoplastics and 139 macroplastics, as an average over 6 locations [83]. Naji *et al.* measured the MP concentration in the mangrove forests of the same general area to be 19.5 to 34.5 particles per kg dry sediment [101]. Maghsodian *et al.* studied MP presence in the Walton's mudskipper (*Periophthalmus waltoni*), inhabiting these mangrove forests. Of 13 mudskippers, 8 contained MP fragments, with 1.1 MP per individual. Mudskippers from the more industrial area Bidkhoun (Nayband Gulf) showed the most MP contamination, while mudskippers from the mangrove forest of the unpopulated Bordekhon area (Nayband Gulf) were found to be free of MP [83]. Interestingly, here, all the MPs found in the bivalves were made of polypropylene.

4.3. MP Status in Fish of Commercial Value in the Arabian/Persian Gulf

Moving on to MP detection in fish of commercial interest (**Figure 3**, **Table 1**), recently, marine species caught in Kuwaiti waters were screened for MP contamination [79]. Here, the gastrointestinal MP contents of the commercially important species orange spotted grouper (*E. coiodes*), silver seabream (*S. hasta*), yellow fin seabream (*Acanthopagrus latus*), and grey (Klunzinger's) mullet (*Liza*

Table 1. MP content of selected fish, crustaceans and molluscs of commercial value.

Fish species	Latin name	Fish family	Marine habitat	Region of the Arabian/Persian Gulf	No. of specimen	MP/fish (mean) (% fish with MP)	Reference
Aulopiformes							
Greater lizardfish	*Saurida tumbil*	Synodontidae	demersal	Musa Estuary (North Western Arabian Gulf)	up to 25	13.5; 0.37/g	[106]
Carangiformes							
Malbar Trevally	*Carangoides malabaricus*	Carangidae	reef-associated	off Ras Abu Ali, KSA	9	0.88 ± 0.35 fibers 0 other MP type	[108]
Malabar Trevally	*Carangoides malabaricus*	Carangidae	pelagic	Bandar Abbas, Iran	17	5.71 (gills) 3.65 (gut)	[107]
Shrimp scad	*Alepes djedaba*	Carangidae		Khark Island North eastern Arabian Gulf		8.00 ± 1.22 per 10 g fish muscle	[104]
Clupeiformes							
Hilsa shad	*Tenualosa ilisha*	Clupeidae	pelagic-neritic	Musa Estuary, Lifeh-Boosif, Bahrekan (North Eastern Arabian Gulf)	12	2.1 ± 0.81	[96]
Mugiliformes							
Gold-spot mullet	*Liza parsia*	Mugilidae	coastal	Tarut Bay, KSA	6	1.55 ± 0.2 fibers (67% of fish) 0 other MP type	[108]
Grey Mullet	*Lisa kluzingri*	Mugilidae	demersal	State of Kuwait	17	0	[79]
Grey Mullet	*Liza kluzingri*	Mugilidae	pelagic	Bandar Abbas, Iran	10	1.40 (gills) 0.16 (gut)	[107]
Grey Mullet	*Liza kluzingri*	Mugilidae	pelagic	Bushehr, Iran		0.257/g muscle	[105]
Abu mullet	*Planiliza abu*	Mugilidae	pelagic	Bushehr, Iran	10	6	[103]
Abu mullet	*Planiliza abu*	Mugilidae	pelagic	Qeshm, Iran	10	0.9	[103]
Abu mullet	*Planiliza abu*	Mugilidae	pelagic	Lengeh, Iran	10	3.6	[103]
Abu mullet	*Planiliza abu*	Mugilidae	pelagic	Bandar Abbas, Iran	10	3.5	[103]

Continued

Abu mullet	*Planiliza abu*	Mugilidae	pelagic	Emam Hassan, Iran	10	1	[103]
Abu mullet	*Planiliza abu*	Mugilidae	pelagic	Hendijan, Iran	10	9	[103
Perciformes							
Longtail silverbiddy	*Gerres acinaces*	Gerreidae	coastal	Tarut Bay, KSA	20	1.05 ± 0.30 fibers (50% of fish) 0 other MP type	[108]
Spangled emperor	*Lethrinus nebulosus*	Lethrinidae	coastal	off Karan Island, KSA	15	1.8 ± 0.88 fibers (33.3% of fish) 0 other MP type	[108]
Spangled emperor	*Lethrinus nebulosus*	Lethrinidae	pelagic	Bandar Abbas, Iran	5	3.00 (gills) 2.60	[107]
Dory snapper	*Lutjanus fulviflamus*	Lutjanidae	Demersal	Bandar Abbas, Iran	2	3.50 (gills) 2.50 (gut)	[107]
Johns snapper	*Lutjanus johnii*	Lutjanidae	demersal	Bandar Abbas, Iran	10	3.20 (gills) 1.10 (gut)	[107]
Malabar Blood snapper	*Lutjanus malabaricus*	Lutjanidae	demersal	Bandar Abbas, Iran	5	3.40 (gills) 1.40 (gut)	[107]
Five-lined snapper	*Lutjanus quinquelineatus,*	Lutjanidae	reef-associated	State of Kuwait (market)			[102]
Tigertooth croaker	*Otolithes ruber*	Sciaenidae	demersal	Bandar Abbas, Iran	10	1.90 (gills) 1.70	[107]
Tigertooth croaker	*Otolithes ruber*	Sciaenidae	demersal	Bandar Abbas, Iran	10	3.2	[103]
Tigertooth croaker	*Otolithes ruber*	Sciaenidae	demersal	Qeshm, Iran	10	15.5	[103]
Tigertooth croaker	*Otolithes ruber*	Sciaenidae	demersal	Lengeh, Iran	10	3.8	[103]
Tigertooth croaker	*Otolithes ruber*	Sciaenidae	demersal	Bushehr, Iran	10	8.5	[103]
Tigertooth croaker	*Otolithes ruber*	Sciaenidae	demersal	Emam Hassan, Iran	10	3	[103]
Tigertooth croaker	*Otolithes ruber*	Sciaenidae	demersal	Genave, Iran	10	0.9	[103]
Tigertooth croaker	*Otolithes ruber*	Sciaenidae	demersal	Hendijan, Iran	10	1.8	[103]
Orange-spotted grouper	*Epinephelus coioides*	Serranidae	reef-associated	State of Kuwait (market)	10	0.3	[79]
Orange-spotted Grouper	*Epinephelus coioides*	Serranidae	reef-associated	Jana Island/Harqus	20	2.1 ± 0.56 fibers (25% of fish) 3 (stomach)	[108]

Continued

Orange-spotted Grouper	*Epinephelus coioides*	Serranidae	reef-associated	Khark Island North eastern Arabian Gulf		7.75 ± 2.16 per 10g fish muscle	[104]
Orange-spotted Grouper	*Epinephelus coioides*	Serranidae	reef-associated	Bushehr, Iran		0.158/g muscle	[105]
White-spotted spinefoot	*Siganus canaliculatus*	Signidae	coastal	off Dammam Port, KSA	20	2.3 ± 0.64 (65% of fish) 1 (stomach)	[108]
Northern whiting	*Sillago sihama*	Sillaginidae	pelagic	Musa Estuary North Western Arabian Gulf	up to 25	14.1; 0.25/g	[106]
Silver sillago	*Sillago Sihama*	Sillaginidae	demersal	Bandar Abbas, Iran	14	0.50 (gills) 1.14 (gut)	[107]
King soldier bream	*Argyrops spinifer*	Sparidae	Demersal	Bandar Abbas, Iran	4	1.75 (gills)	[107]
Silver sea bream	*Sparidentex hasta*	Sparidae	demersal	State of Kuwait (market)	11	0	[79]
Yellow fin sea bream	*Achanthopargus latus*	Sparidae	demersal	State of Kuwait (market)	10	0	[79]
Pleuronectiformes							
Three-lined tongue sole	*Cynoglossus abbreviatus*	Cynoglossidae	meso-pelagic	Musa Estuary North Western Arabian Gulf	Upto 25	12; 0.16/g	[106]
Largescale tongue sole	*Cynoglossus arel*	Cynoglossidae	demersal	Bandar Abbas, Iran	10	7.5	[103]
Largescale tongue sole	*Cynoglossus arel*	Cynoglossidae	demersal	Qeshm, Iran	10	2.8	[103]
Largescale tongue sole	*Cynoglossus arel*	Cynoglossidae	demersal	Lengeh, Iran	10	7	[103]
Largescale tongue sole	*Cynoglossus arel*	Cynoglossidae	demersal	Bushehr, Iran	10	1.2	[103]
Largescale tongue sole	*Cynoglossus arel*	Cynoglossidae	demersal	Emam Hassan, Iran	10	3.2	[103]
Largescale tongue sole	*Cynoglossus arel*	Cynoglossidae	demersal	Genave, Iran	10	1	[103]
Largescale tongue sole	*Cynoglossus arel*	Cynoglossidae	demersal	Hendijan, Iran	10	0.9	[103]
Scombriformes							
Indian mackerel	*Rastrelliger kanagurta*	Scombridae	pelagic	off Jubail, KSA	20	0.66 ± 0.33 fibers (75% of fish) 3 (stomach)	[108]
Indian mackerel	*Rastreliger kanagurta*	Scombridae	pelagic	Bandar Abbas Iran	18	1.56 (gills) 1.22 (gut)	[107]

Continued

Longtail tuna	*Thunnus tonggol*	Scombridae	pelagic	Bandar Abbas, Iran	3	5.67 (gills) 3.00 (gut)	[107]
Mackerel Tuna	*Euthynnus affinis*	Scombridae	pelagic	off Jsafaniya, KSA	20	3.55 ± 0.85 fibers (95% of fish) 0	[108]
Narrow barred Spanish Mackerel	*Scombermorus commerson*	Scombridae	pelagic	Bandar Abbas, Iran	7	4.14 (gills) 4.43 (gut)	[107]
Spanish Mackerel	*Scomberomorus commerson*	Scombridae	pelagic	off Juaymah, KSA	10	0.9 ± 0.31 fibers (60% of fish) 1 (stomach)	[108]
Bigeye barracuda	*Sphyraena forsteri*	Scombridae	pelagic	Bandar Abbas, Iran	10	0.9	[103]
Bigeye barracuda	*Sphyraena forsteri*	Scombridae	pelagic	Qeshm, Iran	10	1	[103]
Bigeye barracuda	*Sphyraena forsteri*	Scombridae	pelagic	Lengeh, Iran	10	2	[103]
Bigeye barracuda	*Sphyraena forsteri*	Scombridae	pelagic	Bushehr, Iran	10	5	[103]
Bigeye barracuda	*Sphyraena forsteri*	Scombridae	pelagic	Emam Hassan, Iran	10	2	[103]
Bigeye barracuda	*Sphyraena forsteri*	Scombridae	pelagic	Hendijan, Iran	10	6.7	[103]
Pickhandle barracuda	*Sphyraena jello*	Sphyraenidae	pelagic	Khark Island North Eastern Arabian Gulf		5.66 ± 1.69 per 10g fish muscle	[104]
Sawtooth barracuda	*Sphyraena putnamae*	Sphyraenidae	pelagic	Bandar Abbas, Iran	3	2.67 (gills) 5.67 (gut)	[107]
Scorpaeniformes							
Bartail flathead	*Platycephalus indicus*	Platycephalidae	demersal	Musa Estuary North Western Arabian Gulf	Up to 25	21.8; 0.59/g	[106]
Bartail flathead	*Platycephalus indicus*	Platycephalidae	demersal	Musa Estuary, Lifeh-Boosif, Bahrekan (North Eastern Arabian Gulf)	12	0.75 ± 0.5	[96]
Bartail flathead	*Platycephalus indicus*	Platycephalidae	demersal	Khark Island North Eastern Arabian Gulf		18.50 ± 4.55 per 10g fish muscel	[104]
Bartail flathead	*Platycephalus indicus*	Platycephalidae	demersal	Bushehr, Iran		0.179/g muscle	[105]

Continued

Bartail flathead	*Platycephalus indicus*	Platycephalidae	benthic	Bandar Abbas, Iran	2	1.50 (gills) 3.50 (gut)	[107]
Gobiiformes							
Walton's mudskipper	*Periophthalmus waltoni*	Oxudercinae	mangrove	Bardestan, Bordekhon, Bibkhoun, Hale-Basatin	14	1.1	[83]
Pteriida							
Pearl Gulf oyster	*Pinctada radiata*	Pteriidae		Bandar-Lengeh, Iran	33	4	[95]
Veneridae							
Asiatic hard clam	*Meretrix meretrix*	Veneridae	benthic	State of Kuwait	13	0	[79]
Venus clam	*Circenita callipyga*	Veneridae	benthic	State of Kuwait	13	0	[79]
Clam	*Amiantis purpuratus*	Veneridae	benthic	Gelkan, Iran	30	6.1	[95]
Clam	*Amiantis umbonella*	Veneridae	benthic	State of Kuwait	13	0	[79]
Clam	*Amiantis umbonella*	Veneridae	benthic	Gelkan, Iran	30	6.9	[95]
Decapoda							
Green tiger prawn	*Penaeus semisulcatus*	Penaeidae	pelagic	Musa Estuary North Western Arabian Gulf	Upto 25	7.8; 1.51/g	[106]
Green tiger prawn	*Penaeus semisulcatus*	Penaeidae	pelagic	Bushehr, Iran		0.36/g muscle	[105]
Green tiger prawn	*Penaeus semisulcatus*	Penaeidae	pelagic	Musa Estuary, Lifeh-Boosif, Bahrekan (North Western Arabian Gulf)	103	0.62 ± 0.25	[96]
White shrimp	*Metapenaeus affinis*	Penaeidae	benthic	Musa Estuary (North Western Arabian Gulf	NA	1.02	[97]
White shrimp	*Metapenaeus affinis*	Penaeidae	benthic	Musa Estuary, Lifeh-Boosif, Bahrekan (North Western Arabian Gulf)	151	0.45 ± 0.23	[96]
Blue swimmer crab	*Portunus armatus*	Portunidae	benthic	Bushehr, Iran		0.256/g muscle	[105]
Blue swimming crab	*Portunus pelagicus*	Portunidae	Reef-associated	Musa Estuary, Lifeh-Boosif, Bahrekan (North Western Arabian Gulf)	44	2.29 ± 1.13	[96]
Gastropoda							
Snail	*Thais mutabilis*	Muricidae		Angur, Iran	6	17.7 ± 0.3	[95]
Girdled horn shell	*Cerithidea cingulata*	Potamididae		Angur, Iran	24	4	[95]

klunzingeri), the bivalves *Meretrix meretrix* and *Amiantis umbonella* and the Venus clam *Circenita callipyga* were investigated [79]. Strikingly, MP was only discovered in the orange-spotted grouper, albeit only 3 MP in altogether 10 grouper specimen. As noted above, this result reflects the reported paucity of MPs in Kuwaiti waters and in Kuwaiti beach sediments. This was strengthened by a study of Al Salem *et al.* [102] of nine fish species from Kuwaiti water, namely the orange spotted grouper (*E. coioides*), the sea catfish (*Plicofollis layardi*), the yellowfin seabream (*Acanthopagrus latus*), the fourfinger threadfin (*Eleutheronemaa tetradactylum*), silver pomfret (*Pampus argenteus*), Klunzinger's mullet (*L. klunzingeri*), the Javelin grunter (*Pomadasys kaakan*), and five lined snapper (*Lutjanus quinquelineatus*) (1 specimen each), where MP content was found only in *A. latus*, *E. tetradactylum* and *L. quinquelineatus* [102]. Agarokh *et al.* [103] sampled *Otolithes ruber*, *Liza abu*, *Sphyraena forsteri*, and *Cynoglossus arel*, where the fish were bought from local fishermen in the regions of Hendijan, Genave, Emam Hassan, Bushehr, Bandar Abbas, and Lengeh (all Iran). Bushehr, Qeshm, and Hendijan were found to be the most polluted region based on the numbers of MPs in the investigated species. Overall, 28.5% of the fish (n = 248) in this study had MP in their gastrointestinal tract. The tigertooth croaker (*O. ruber*, 0.43 ± 0.12 MP/individual), the Abu mullet *(L. abu*, 0.34 ± 0.09 MP/individual), the largescale tongue sole (*C. arel*, 0.33 ± 0.14 MP/individual), and the Bigeye barracuda (*S. forsteri*, 0.24 ± 0.08 MP/individual) were the fish species with the highest MP count [103]. Agharok *et al.* [103] found no correlation between MP abundance in surface water, sediment, and fish samples. R. Akhbarizadeh *et al.* looked at the MP concentration in 4 fish species purchased from fish-mongers on Khark Island. The bartail flathead (n = 16, *Platycephalus indicus*) had the largest MP abundance with an average of 18.50 ± 4.55 items/10 g fish muscle, and the pickhandle barracuda (n = 15, *Sphyraena jello*) had the lowest abundance of MPs with an average of 5.66 ± 1.69 items/10 g fish muscle. Moreover, the average abundance of MPs in muscles of the shrimp scad (n = 20, *Alepes djedaba*) and of the orange-spotted grouper (n = 20*, E. coioides*) were 8.00 ± 1.22 and 7.75 ± 2.16 items/10 g fish muscle, respectively [104]. This led the authors conclude that benthic fish are most exposed to MPs [104]. Also, R. Akhbarizadeh *et al.* looked at the MP concentration in muscles and gills of five popular commercial species (3 fish, 1 crab, and 1 prawn) from Iranian water of the Gulf as potential edible parts of the marine organisms to understand the risk of the human intake of MP through seafood from the region [105]. The green tiger prawn (*P. semisulcatus*) and the orange-spotted grouper (*E. coioides*) displayed the highest (mean 0.360 items/g muscle) and lowest (mean 0.158 items/g muscle) MP concentration, respectively [105]. The MP concentration was higher in the gills than in the muscle of the analyzed species. This was especially true for scavengers and filter feeders such as *L. klunzingeri*, *P. armatus*, and *P. semisulcatus*. The results of the trophic magnification factor (TMF) and biomagnification factor (BMF) calculations indicated that MPs were not biomagnified in the edible parts of the marine organisms of the Persian Gulf. It seems that, contrary to previous belief, MP trophic dilution occurs rather than magnification in the edible parts of seafood [105]. Abbasi *et al.* [106] investigated four fish species and one crustacean in the Musa Estuary, Iran for MP contamination. The bartail flathead (*P. indicus*) had an average MP concentration of 0.59 particles/g, the greater lizardfish (*S. tumbil*) 0.37 particles/g, the Northern whiting (*Sillago sihama*) 0.25 particles/g, the tongue sole (*Cynoglossus abbreviatus*) 0.16 particles/g and the green tiger prawn (*P. semisulcatus*) 1.51 particles/g. In 2021, Hosseinpour *et al.* [107] reported on MP contamination of 16 species of fish caught in the general area of the Strait of Hormuz. The 16 species are the Indian mackerel (n = 18, *Rastreliger kanagurta*), the sawtooth barracuda (n = 3, *Sphyraena putnamiae*), Klunzinger's mullet (n = 10, *L. klunzingeri*), the Northern whitling (n = 14, *S. sihama*), John's snapper (n = 10, *Lutjanus johni*), the Spanish mackerel (n = 7, *Scomberomorus commerson*), the Malabar blood snapper (n = 5, *Lutjanus malabaricus*), the tigertooth croaker (n = 10, *O. ruber*), spangled emperor (n = 5, *L. nebulosus*), and the Malabar trevally (n = 17, *C. malabaricus*), the king soldier bream (n = 4, *Argyrops spinifer*), Dory snapper (n = 2, *Lutjanus fulviflammus*), the bartail flathead (n = 2, P. *indicus*), and the longtail tuna (n = 3, *Thunnus tonggol*). The fish specimens from areas near Bandar Abbas, Minab and Bandar Lengeh were found to be contaminated with MPs [107]. The maximum mean abundance of MPs was observed in the gill (5.71 particles/individual) of *T. tonggol* and in the gut tissue (5.67 particles/individual) of *S. putnamiae*. A significant positive correlation between the total fish length and the abundance of MPs was observed. MPs were found to be more abundant in pelagic fish (5.79 ± 5.98 particles/individual) than in demersal fish species (3.89 ± 3.53 particles/individual) [107]. In a critical evaluation of nine common commercial important fish species (*Liza parsia*, *Gerres acinaces*, *L. nebulosus*, *E. coioides*, *R. kanagurta*, *Eythynnus affinis*, *S. commerson*, *Carangoides malabaricus*, *Siganus canaliculatus*) off the Saudi Arabian coast, Baalkhuyur *et al.* [108] found that only 1 in every 20 fish (5.71%) examined had ingested microplastic apart from microfibers. Spangled emperor (*L. nebulosus*, n = 15), the longtail silver-biddy (*G. acinaces*, n = 20), the goldspot mullet (*L. parsia*, n = 6), the mackerel tuna (*E. affinis*, n = 20), and the Malabar trevally (*C. malabaricus*, n = 9) were found to be completely free of MP that were not microfibers. However, microfiber ingestion was relatively common, with 95% of the investigated mackerel tuna (*E. affinis*) exhibiting MP contamination at levels of 3.55 ± 0.85 fibers per fish. Also, 75% the examined Indian mackerel (*R. kanagurta*) and 60% of the Spanish mackerel *(S. commerson*) showed fiber contamination [108]. Although in much of the work from other authors, microfibers are included within the MP count, this is a lower ingestion rate than observed for fish in other seas in the MENA region such as in the Red Sea [56] or in the Mediterranean Sea [55]. There has been some discussion that MP contamination in the muscles of fish could be caused in part by procedural contamination [107]. Although there are studies on mechanisms of the entry of MPs into muscle tissue of fish and other organisms [109] [110], this point may need to be revisited.

In their review, Lyons *et al*. [60] have commented that there is yet limited data in regard to MP concentrations in the area of the Arabian/Persian Gulf. Thus, data is yet missing of fish caught and/or sold in the United Arab Emirates, Qatar, Oman (on the side of Arabian/Persian Gulf) and Bahrain. The low MP concentrations measured in Kuwaiti intertidal zones and in Kuwaiti waters are surprising. Also, measurements coming out of Saudi Arabia give MP concentrations in fish that are much below MP concentrations found in fish from the Mediterranean Sea or near parts of the Atlantic coastline. Higher MP concentrations have been measured on the Northern coast of the Arabian/Persian Gulf, where also the larger share of the data stems from. As the region of the Arabian/Persian Gulf is undergoing rapid change, it would be helpful to collect more data in regard to MP presence in soil/sediments, water and marine organisms of the region to have a baseline against which any changes, including legislative changes in respect to single use plastic utilization, can be evaluated at a later time. This could well be supported by modeling of the transport and distribution of MPs in the Arabian/Persian Gulf [111].

5. Conclusion

While there is yet a paucity of data on MP concentrations in the area of the Arabian/Persian Gulf, recent studies have started to fill this gap. Relatively low concentrations of MP have been found in commercial fish along the Kuwaiti and Saudi Arabian coastline. Little data on MP ingestion of fish along the coasts of Qatar, Bahrain and the United Arab Emirates is available. Higher MP concentrations are found in marine organisms along the Iranian coastline. All in all, currently, the published MP concentrations in commercial fish from the Arabian/Persian Gulf are lower than those from the Mediterranean Sea. As the countries surrounding the Gulf are experiencing population growth and the coastline of the Gulf is changing under anthropogenic pressure, monitoring of MP concentration in the Gulf will need to continue.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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