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Microplastics in the Mediterranean Sea: Sources, Pollution Intensity, Sea Health, and Regulatory Policies

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Microplastic pollution is one of the emerging threats across the globe and is becoming a topic of intense study for environmental researchers. At present, almost all of the world's oceans and seas are contaminated with microplastics but the Mediterranean Sea has been recognized as a target hotspot of the world as the microplastic concentration in this region is approximately four times greater than the North Pacific Ocean. Because of the distinguishing semi-enclosed morphology of the Mediterranean Sea, and different plastic waste generating activities originating from surrounding countries the Mediterranean Sea is highly vulnerable to microplastic pollution. Different plastic families have been reported in the Mediterranean Sea and the Physico-chemical features of these plastic polymers play an important role in the interactions between these plastic particles and other organic matter in the water bodies. The ingestion of microplastics by marine animals is an issue of concern as microplastic acts as vectors for other harmful pollutants adsorbed onto their surface. This review provides a detailed discussion on the persistence of microplastics in the Mediterranean Sea that have been identified in surface water and also in sediments and deep sea-floor. Various sources of these synthetic materials and the intensity of low and high-density polymers pollution in the Mediterranean Sea have also been discussed. This review also focuses on the threatened species in the Mediterranean Sea and the fate of the plastisphere community in its ecosystem. In the end, we highlight a series of important regulations and policies adopted by Mediterranean countries to control and manage the microplastic pollution in this region.

Keywords: microplastics, plastic litter, Mediterranean Sea, plastisphere, marine animals, regulatory policies

INTRODUCTION

In the 21st century, the problem of plastic pollution has emerged as a perilous threat to human and environmental health (Amaral-Zettler et al., 2020). The global utilization of plastic polymers was approximately 300 million tons in 2018 and the size of the global plastic market in 2019 was approximately USD 568.9 billion. This amount is expected to rise at a compound annual growth rate of approximately 3.2% from a period of 2020–2027 (Market analysis report, 2020), and by the end of 2050, the production rate of plastic is expected to amplify 4–5 folds covering 20 and

15% of oil burning and worldwide carbon budget respectively (Neufeld et al., 2016). The lower rate of recycling activity and enhanced utilization of single-use plastic products are some of the careless activities which are worsening plastic pollution. According to a study based on a global analysis of plastics in 2017, it was discussed that globally 8.3 billion metric tons of plastic were produced in which 6 billion metric tons were converted into plastic waste and only 9% of plastic was recycled (Geyer et al., 2017). This is one of the major causes for the accumulation of a large quantity of plastic debris (∼79%) in our surrounding environment. With this trend, it is expected that by the end of 2050, approximately 12 billion tons of plastic will be accumulated in landfills (Parker, 2018). The persistent plastic debris in the environment undergoes degradation upon exposure to different environmental factors such as sunlight, water, wind, and broken down into tiny plastic particles known as microplastics (1–5000 μm) (5 mm), and nano plastics (<1 μm) (Sharma and Chatterjee, 2017). After fragmentation, these plastic particles are heading toward marine bodies in the form of pellets, fibers, and granules. Microplastics are ubiquitous and their presence has been noticed in aquatic bodies, ocean sediments, and in the deep-sea sediments of the extreme Arctic and Antarctic regions (Wright and Kelly, 2017). The microplastics act as a vector of various toxic additives and pollutants by accumulating and binding these toxic agents from the surrounding aquatic environment and thus offer habitat to different microbial communities (Suaria et al., 2016). Due to the small size of microplastics, the ingestion of these tiny fragments by the marine organisms is very frequent and thus has an adverse impact on their health along with the concerning issue of transfer of these toxic microplastics to higher trophic levels (Chatterjee and Sharma, 2019). Several evidence-based research has recently pointed out that exposure of humans to microplastics is very plausible through the daily consumable food items as tiny plastic particles were detected in different seafood, processed food articles, and in beverages (e.g., sugar, salt, and beer) (Smith et al., 2018; Llorca et al., 2020).

The significant problem of microplastic pollution in the coastal regions is a matter of concern as increasing population density, tourism, marine harboring and coastal activities are contributing to a great extent to the release of complex and toxic contaminants including daily used plastic items. It is estimated that approximately 8.8 kg/capita/year of macroplastics and 0.18 kg/capita/year of microplastics are released into marine bodies as a result of different coastal activities (Van-Wijnen et al., 2019). The menace of plastic pollution has created an alarming situation across the globe and thus different initiatives have been started on a global scale. One of the leading initiative taken by the European Marine Strategy Framework Directive (2008/56/EC) has emphasized the rising concerns for environmental repercussions of marine waste and also highlighted the urgent requirement for its member countries to establish trends regarding the composition and distribution of microplastics in European aquatic bodies along with their properties and potential impacts (Galgani et al., 2010; Agamuthu et al., 2019). This issue of marine litter has been recognized by the member parties in the Barcelona Convention and also by the G7 globe leaders (the organizations who are committed to a global plan to battle marine litter) (G7 Summit Declaration, 2015). Apart from that, a vast number of scientific reports have been published which discussed the existence and estimation of microplastics in an aquatic habitat, specifically, in the ocean ecosystem (Waller et al., 2017), and the freshwater habitat (Horton et al., 2017; Li et al., 2018). The presence of microplastics has been assessed in different geographical ecosystems such as freshwater habitat in the Asian region (Fu and Wang, 2019), gyres of the subtropical region (Thiel et al., 2018), the North Pacific gyre (Bryant et al., 2016), the Antarctic aquatic habitat (Sfriso et al., 2020), the Atlantic oceanic bodies (Costa and Barletta, 2015; Monteiro et al., 2018), and the Mediterranean Sea (Lebreton et al., 2012). The Mediterranean Sea has been recognized as the sixth-highest accumulation hotspot for marine litter (Cozar et al., 2015). Various types of plastic particles are found in coastal areas, beaches, on the sea surface, and on the seafloor which is accounted for nearly 30 thousand tons of plastic mass in the Mediterranean basin (Van Sebille et al., 2015). To overcome this severe plastic pollution in the Mediterranean region, the European Union (EU) has formulated different strategies for the immediate preservation/remediation of different parts of the Mediterranean Sea.

This review provides a detailed insight regarding the abundance of microplastics in the Mediterranean Sea, the effect of microplastic pollution on the marine species inhabiting the Mediterranean Sea, and the fate of the plastisphere community in its ecosystem. This review also provides detailed information on different legislative policies adopted by the neighboring countries for effective control of microplastic and plastic pollution.

MICROPLASTIC POLLUTION IN THE MEDITERRANEAN SEA

Intensity of Plastic/Microplastic Pollution in the Mediterranean Sea and Mediterranean Basin

The vulnerability of the Mediterranean Sea to plastic pollution is due to its distinguished semi-closed configuration surrounded by three continents with dense populations (∼150 million) that act as a trap for plastics debris (WWF, 2018). Different shipping, fishing, industrial, touristic, and other coastal activities are also contributing largely to the Mediterranean Microplastic pollution. The Mediterranean basin is producing approximately 208–760 kg per year solid waste per capita (Alessi and Carlo, 2018), and tourist activities in the Mediterranean basin are one of the great contributors to this increased marine litter (Galgani et al., 2014). The leading coastal countries dumping a significant amount of plastics are Spain (126 tons/day), Turkey (144 tons/day), Italy (90 tons/day), France (66 tons/day), and Egypt (77 tons/day) (UNEP/MAP, 2015). A 2D Lagrangian model study was conducted by Liubartseva et al. (2018) to track the plastics in the Mediterranean region and more than 1010 virtual plastic fragments were traced from the coastal human-populated areas, rivers, shipping lanes to the sea surface, coastlines, and seabed. The Mediterranean basin collects water from different highly populated river catchments (Nile, Rhone, Po) and is also connected by the Strait of Gibraltar to the Atlantic Ocean. It is traversed by various shipping lanes and has a diverse water circulation pattern for the collection and accumulation of floating debris (floating plastics in the Mediterranean Sea). The authors have found that plastic particles were not accumulated in the sea-surface but piled up substantially on coastlines and the sea bottom. An ample amount of plastic litter was found in the Cilician subbasin, Catalan Sea, and near the Po River Delta. Among cities, Barcelona, Alexandria, and Izmir are the major plastic debris contributing cities in the Mediterranean Sea (**Table 1**). They used an inverse problem solution to quantify the origins of these plastic fragments and concluded that terrestrial sources of every Mediterranean country are responsible for the Mediterranean plastic pollution (Liubartseva et al., 2018). This massive amount of plastic debris after accumulating in the Mediterranean Sea undergoes fragmentation into smaller pieces after a certain period (Guven et al., 2017). In Mediterranean surface waters, plastic contamination is dominated by a range of millimeter-sized plastic fragments (Suaria et al., 2016; van der Hal et al., 2017; Schirinzi et al., 2019) and also by a relatively high proportion of mesoplastics (Alomar et al., 2016; Gundogdu and Çevik, 2019); while the presence of microplastics is highest in sediments (Van Cauwenberghe et al., 2013; Abidli et al., 2018). Today, an average of 95% of the plastic waste has been reported across the Mediterranean including sea waters, onto the seabed, and also on beaches (UNEP/MAP, 2015). Each year approximately 500,000 tons of macroplastics and 130,000 tons of microplastics penetrate in European sea (European Commission, 2018), and an immense portion of these plastic fragments make their way to the Mediterranean Sea (Alessi and Carlo, 2018). It was found that the Mediterranean basin is the major hotspot for plastic litter with 7% of global microplastics (Suaria et al., 2016). The distribution of plastic and microplastics along the coastline (specifically on beaches) has been recorded in various studies (Lebreton et al., 2012; Antunes et al., 2018; Constant et al., 2019), and it was estimated that the average plastic concentration in the oceans is approximately 2 ng/L (Koelmans et al., 2016). The dense accumulation of plastic has been reported in the Atlantic beaches near urban and industrial areas with port amenities (Antunes et al., 2018) and the Mediterranean Sea could build up floating plastic debris in a range of 1,000 and 3,000 tons (Cozar et al., 2015) making it worst affected marine habitats (Lebreton et al., 2012).

The accumulation of floating plastic debris in the Mediterranean Sea was first reported by Morris (1980), and by adopting a quantitative analytical survey, approximately 1,300 plastic materials per square kilometer were reported in the central province of this basin. The surface pollution was quantified by using specific surface net tows which allows the detection of minute-sized plastic fragments in the coastal regions of southern France (Collignon et al., 2012; Eriksen et al., 2014), western Sardinia (de Lucia et al., 2014), and northwestern Italy. Lebreton et al. (2012) modeled the distribution and transport of floating plastic debris in the ocean by estimating inputs from both terrestrial and marine sources. The simulation study of this model declared the Mediterranean Sea as one of the potential plastic accumulation zones. This model was also considered for the estimation of the load of surface plastic in the Mediterranean Sea which was approximately 23,150 tons (Eriksen et al., 2014). It is evident from various studies that the major quantities of these plastics might be deposited on the ocean floor, and also in water columns and the deep ocean currents are playing an important role in the distribution of microplastics onto the seafloor. In a model study based on ocean currents, the sediment samples from the seafloor of the renowned Tyrrhenian Sea (part of the Mediterranean Sea, **Figure 1**) was analyzed and it was found that microplastic concentration was lesser in samples obtained from such channels where there were strong ocean currents whereas, the concentration of microplastics in the samples was relatively high where channels were exposed to slow ocean currents. It was recorded that there were around 1.9 million microplastic particles per square meter of seafloor sediment of Italy (Dunphy, 2020). Thus it was evident from the study that apart from floating plastic patches, microplastics are also present at high concentrations in the deep seafloor of the Mediterranean Sea (Kane et al., 2020).

TABLE 1 | Major sources of Marine litter in the Mediterranean Sea with pollution intensity.

Major sources of marine litter in the mediterranean sea			Pollution intensity (Tons/year)
Cities/Country	Barcelona	Spain	1787
	Izmir	Turkey	1562
	Algiers	Algeria	1.22
	Alexandria	Egypt	2209
	Tel Aviv	Israel	3278
Rivers and water-way system/Country	The Po Delta	Italy	1350
	Ceyhan	Turkey	5109
	Seyhan	Turkey	3465
	Nile	Egypt	6772
	Rhone	France	1454
	Buyuk Menderes River	Turkey	2406
Shipping lanes	International		20,000

The table was constructed after extracting data from Liubartseva et al. (2018).

Different Sources of Mediterranean Microplastic Pollution

Sources of marine debris are classified into two categories, land-based and sea-based depending on the entry point of marine litter. In a recent study, it has been calculated that total annual plastic input in the Mediterranean basin is equal to 100,000 tons, and of these 50% of the plastic litter generally originates from various land-based sources, while 30% of trash is from river channels and 20% is from maritime routing (Cincinelli et al., 2019). The vast coastal population (approximately 150–160 million residents), tourism activities ($\sim$350 million tourists stays overnight per year), and managing this debris in unprotected landfills (without undergoing recycling) are generally considered as the root causes for the generation of marine litter in the

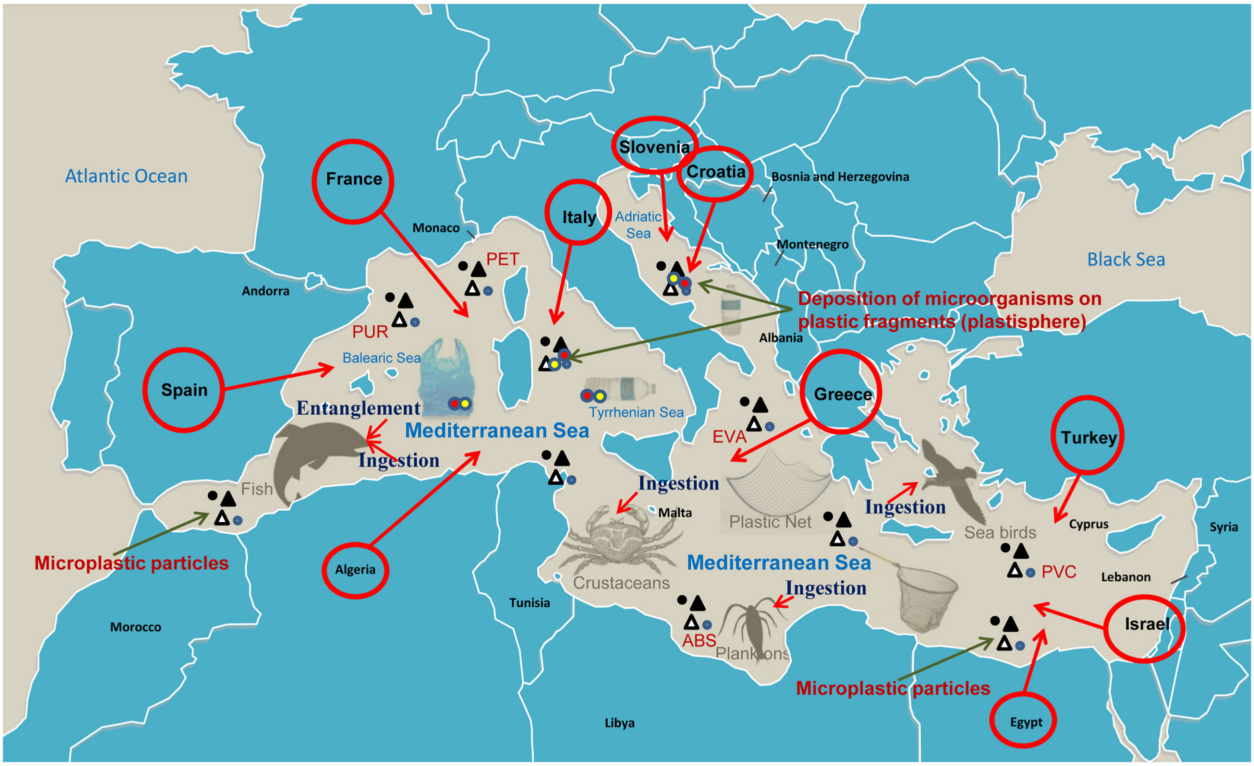

FIGURE 1 | An overall representation of Mediterranean Microplastic pollution. The countries that contribute to the major amount of plastic litter and microplastics in the Mediterranean Sea are marked with red color. Plastic families found on the Mediterranean coast and in the Mediterranean Sea are also mentioned on the map. The plastisphere and the marine animals (inhabiting the Mediterranean Sea) affected due to entanglement and ingestion are shown separately (Map source: https://yourfreetemplates.com).

Mediterranean Sea (Prevenios et al., 2018). The entry of plastic litter from different land-based sources is attributed to 21 nations located on three different continents and these sources are generally comprised of usual domestic, industrial, business, and touristic activities. This can be explained by the example of Europe where there is enormous production of plastic waste and the majority of this debris is dumped into landfills which will then make its way to the Mediterranean Sea in every passing year via wastewater streams, rivers, stormwater runoffs, and by wind currents. Ocean-based sources of plastic litter include cruise liners, merchant shipping, commercial and fishing activities, military fleets, pleasure crafts, and other offshore activities such as oil and gas stations, aquaculture sites, and drilling activities. These mega, macro and meso plastics in Sea are then fragmented into tiny microplastics causing a serious threat to marine biota and finally to human health (WWF, 2018). It is estimated that approximately 94% of these tiny plastic fragments accumulated on the seafloor, 5% gathered onto beaches, and the remaining 1% on the surface of oceans (Sherrington, 2016). Following are the few neighboring countries that contributed to *Mediterranean Microplastic pollution* significantly.

Italy

Italy consumes approximately 2.1 million tons of plastic items per year and the majority of which are single-use plastics. The population of Italy is being considered as a supreme consumer of plastic water bottles across Europe with a percentage range of 70%, and 32 million single-use plastic bottles are being dumped by each passing day in Italy. Apart from that, the process of recycling is very limited (40%) leading to the massive dumping of plastic waste into the sea (Alessi and Carlo, 2018).

Spain

The Spanish population is consuming 3.84 million tons of plastic items each year among which only 35–38% of plastic is subjected to recycling. Approximately 10% of single-use plastic across Europe is being consumed by Spanish people including 3500 million plastic bottles, 1500 million plastic cups, 5000 million plastic straws, and 207 million disposable containers (Sherrington et al., 2017). In coastal areas like Granada and Almeria, a significant presence of greenhouse plastics (specifically used for agricultural purposes) has been noticed that possibly routed toward the Mediterranean Sea through windstorms, wastewater streams, and rivers (Alessi and Carlo, 2018).

Greece

An average of 6 million tons of plastic items are consuming by the Greek population every year, and only a small percentage of this litter (20%) is been recycled. According to a survey, the most abundant litter on beaches was plastic (51%) followed by paper (10%) and aluminum (12%). The presence of plastics is in the form of plastic bags, plastic bottles, and plastic containers.

The inefficient solid waste management in the country is also contributing to the *Mediterranean Microplastic pollution* (Kordella et al., 2013; UNEP/MAP, 2015).

France

Approximately 2–4 million tons of plastic items are consumed in France and the population of France is being considered as the top three plastic consumers across Europe. The single-use plastic items such as plastic bags and plastic bottles are the great contributors to the *Mediterranean Microplastic pollution*, whereas, poor plastic waste recycling (only 21%) are creating a more wretched situation resulting in disposing of a major portion of plastic litter in the marine bodies (Alessi and Carlo, 2018).

Croatia

In 2016, about 54744 tons of packaged plastic was used in Croatia and smaller polystyrene products were among the most commonly utilized items. In the Croatian seas, the major plastic items found were plastic bottles, plastic straws, and plastic caps. The recycling rate in the country is very low with only half of the produced plastics are recycled (Jovičić, 2017).

Turkey

According to a report published in the year 2017, Turkish people has utilized an average of 1.24 million tons of plastic in 2015, and only 35–40% of plastic waste was recycled and the rest of the waste was filled in the unprotected landfills (Gundogdu and Çevik, 2017).

Plastic Families Found on the Mediterranean Coast Which Contribute to Mediterranean Microplastic Pollution

In the Mediterranean Basin, the presence of plastic has been reported in the form of polyester foam, filaments of fishing gears, and other small plastic fragments covering a diverse chemical composition. In a study conducted by Marine Geosciences, it was found that polymers such as polyethylene, polystyrene, polyester, and polypropylene were the most abundant form of microplastics found in the Mediterranean Sea (de Haan et al., 2019). One determining point of the plastic study is the density of plastic polymers which affects the buoyancy of microplastics. The global production of polyethylene is in the range of 80–85 million tons annually (Bayo et al., 2018) and the primary use of this polymer is for packaging. Polyethylene is lightweight, flexible, easy to process and a high chemical-thermal resistance compound which makes it an ideal contender for various daily use applications. Polyethylene is the dominant form of polymers in the Mediterranean Sea which exists in both forms of high-density polyethylene (HDPE) and low-density polyethylene (LDPE). The HDPE is a solid, colorless lightweight rigid thermoplastic polymer composed of ethylene units with high acid resistance property and is used in plastic containers, motor oil, detergent, etc. The LDPE has high flexibility than HDPE and due to its easy processing, it is used as a constituent in supermarket plastic bags and also used as a wrap for different food products (Bayo et al., 2018). Analysis of approximately 2,500 plastic samples taken from various zones of Mediterranean regions showed that the most abundant plastic polymers were polyethylene (54.5%) followed by polypropylene (16.5%) and polyester (9.7%) (de Haan et al., 2019). In the year 2018, the global production volume of polypropylene was 56 million metric tons (Garside, 2020), and was mostly used for the plastic packaging formulation of various food articles as this polymer can withstand a higher range of temperatures. Vinyl-polychloride is another largest consumed plastic polymer with a production scale of approximately 30 million tons (Bayo et al., 2018). It is rigid, stable, and inert and can be utilized for electric wiring purposes. In a study to detect microplastics in the peninsular coastal region of the Mediterranean Sea, it was observed that the dominant plastic polymers present were, polyethylene terephthalate (PET), acrylonitrile butadiene styrene (ABS), ethylene-vinyl acetate (EVA), polyvinyl chloride (PVC), and polyurethane (PUR). The coastal region of Catalan has a microplastics concentration of over 180,000 items per square kilometer and polyethylene was abundant with a concentration of approximately 65%. This is due to the extreme anthropocentric pressure related to high population density, tourism, and all the marine activities on the beaches of Catalan. In the coastal waters of Almeria and Murcia, a variety of plastic polymers (both high and low density) such as PUR, PET, and nylon are dominating. It was also found that the appearance of these polymers is diverse comprising matt (54% in Almeria and 46% in Murcia) and gloomy (12% in Murcia and 20% in Almeria). The diversity in both these coasts is due to the entry of waters from the Strait of Gibraltar which favor the diverse emergence of microplastics in the sea (de Haan et al., 2019). The movement of ships has also influenced marine pollution in the Adriatic Sea which leads to the deposition of paint polymers and paraffin wax in the seawater. The synthetic paint polymers are produced during the maintenance, repair, and cleaning of ship decks (Turner, 2010) and other intense marine shipping activities (Song et al., 2014). Paraffin wax is utilized for insulation purposes and also acts as a corrosion protective agent in marine handles and candle construction. These polymers are transported in huge quantities by marine cargo ships and used to discharge at specific areas of the Mediterranean Sea (UEG, 2014). It was discovered in a study that paraffin wax clumps were present in the coastal regions of the Baltic Sea and also traces of these paraffin clumps were reported in the gut of fulmars (a seabird habitat to this region) (Van Franeker et al., 2011; Esiukova, 2017). Another petroleum-based polymer polycaprolactone (PCL) which is used in different biomedical applications and 3D printing activities is also highly abundant in the Mediterranean off-shore waters (UNEP, 2015). About 66% of microplastics, composed of low-density polymers of polypropylene, polyethylene, and polystyrene were present as marine aggregates (mainly consist of smaller and more angular microplastics) in the Mediterranean Sea, and after a certain period deposited at the bottom of the sea (de Haan et al., 2019).

Microplastic in Sediments, Coastal Regions, and Sea Floors

Plastics with a higher density than seawater (1.02 g/cm^3) tend to sink and build up in the sediment whereas, low-density polymers are bound to float onto the surface or can be maintained in the water column as suspension (Chubarenko et al., 2018). Other than density, shape, and chemical composition of the plastic particles are also played a significant role in determining their mobility in the aquatic environment. The process of biofouling which is associated with microplastic fragments and certain organic materials and also with microorganisms can fabricate a density modification which ultimately favors the sinking of plastic and microplastics debris in the water.

Microplastics in Sediments

The sediments of the Mediterranean Sea are one of the most obvious sinks for microplastics deposition and have an immense potential for their accumulation (**Table 2**). The occurrence of microplastics in western region sediments of the Mediterranean Sea was analyzed and it was found that microplastics (per kilogram of dry weight) ranged from 45.9 ± 23.9 in Palma de Mallorca to 280.3 ± 164.9 in Malaga (Filgueiras et al., 2019). In another study on the sediments of the Cabrera region in the Balearic Island, the concentration of microplastics was relatively higher i.e., 0.90 ± 0.10 microplastics/g in comparison to the touristic spot Mallorca region of Balearic Islands. This is due to the transfer of microplastics from its source areas (Mallorca region) to endpoint areas (Cabrera region) proving that anthropogenic factors along with environmental factors play an important role in the transport of microplastics across different sediments (Alomar et al., 2016). The first observations of microplastics in sediment samples of Venice lagoons which is a northeastern city of Italy was analyzed and the total abundance of these polyethylene and polypropylene plastic fragments were found 2175 to 672 microplastics/kg dry weight with a size range of 30–500 mm (Vianello et al., 2013). The microplastic trash recovered in the sediments of the Tyrrhenian Sea in Italy depicted that various agricultural practices were the key source of plastic pollution and the values of this microplastic deposition varied in a range of 45 and 1069 microplastics/kg dry weight (Guerranti et al., 2017).

The study of sediments in the central Adriatic Sea of the Mediterranean basin (Mistri et al., 2017) showed that a broad range of plastic fragments was deposited in which 65.1% was accounted for microplastics, and 30.3 and 4.6% were comprised of meso-plastics and macro debris respectively. The extensive distribution of microplastics in the sediment of the Northern Tunisian coast revealed that the concentrations of these tiny sized fragments were ranged from 141.20 ± 25.98 to 461.25 ± 29.7 microplastics/kg dry weight and the plastic polymers mainly were polyethylene, polypropylene, and polystyrene with a dimension of 0.1–5 mm (Abidli et al., 2018).

Microplastics on Beaches

Microplastic fragments are ubiquitous in coastal areas and the extensive touristic activities in the Mediterranean basin are considered as the main reason for the beach pollution which not only harms the coastal ecology but also ruins the quality of seawater (**Table 2**). Considering various published reports it is clear that plastic items are the dominant constituents of the beach litter, and detected on the beaches of Israel (∼90%) (Pasternak et al., 2017), eastern Italy (∼81.1%) (Munari et al., 2016), Slovenia (∼ 64%) (Laglbauer et al., 2014), and Greece (∼51%) (Kordella et al., 2013). The samples collected from two important beaches of the northern and southern locations of the western Gulf of Lion showed a higher concentration of toxic microplastics ranging from 33 to 798 microplastics/kg of dry weight (in the northern beach) to 12–187 microplastics/kg of dry weight (in the southern beach). This temporal distribution of microplastics on beaches is dependent on various external forces such as wind currents, precipitation rate, outflow layer, and finally on the proximity of the river mouth (Constant et al., 2019).

Microplastics on the Seafloor

An analysis in the *trans*-Mediterranean Sea found that plastic litter is omnipresent at all depths from 900 to 3000 m (Ramirez-Llodra et al., 2013). It was also found that a higher concentration of microplastics (92%) was present on the seafloor, nearer to the shore across the central, western, and eastern Mediterranean (Pham et al., 2014). The authors pointed out that the distribution of such marine litter is governed by a few factors including wind and wave currents, storms, and hurricanes. Another study showed that the seafloor of La Fonera and Cap de Creus canyons in the northwest region of the Mediterranean Sea has accumulated a huge concentration of marine litter over the two years (approximately 8,000 microplastics items/km^2 collected from the central and northern Adriatic Sea) (Tubau et al., 2015). In the trawler study conducted by Strafella et al. (2015), a vast amount of plastic litter was detected on the seabed closer to the shore and up to a depth of 50 m. A study conducted on the different seabed located in the Tyrrhenian Sea, Sardinia, and Sicily found an appreciable quantity of plastic debris on the rocky seafloor of the Tyrrhenian Sea.

THE *PLASTISPHERE* IN THE MEDITERRANEAN BASIN AND ITS FATE

Nowadays the problem of plastic pollution is one of the serious threats to our ecosystem. Regular use of these toxic products in our daily life and improper management practices are not only creating an enormous number of hazardous environmental health effects but also contributing a few million tons of plastic litter into the aquatic ecosystem. Once these synthetic plastic fragments enter the marine environment, these are colonized by a range of microorganisms which include diatoms, bacteria, and fungi which tend to form biofilm on the surface of plastic polymer. This has been described by a term known as *plastisphere* which is an ecosystem of association of microorganisms and plastic fragments in which microbes colonize and sustain on plastic debris (Zettler et al., 2013). The plastisphere is particularly dominated by a range of prokaryotes adapted to thrive on plastic and even have a tendency to metabolize it. Specifically, the bacterial populations of the plastisphere include those bacterial strains that are capable of synthetic polymers degradation. In this case, the degradation rate is slow and the mechanism of development of this association is yet not understood (Bryant et al., 2016; Debroas et al., 2017). In this context, diverse

TABLE 2 | Microplastics found in sea sediments and beaches around the Mediterranean Sea.

Places from where samples were collected	Average items/Kg sediment (dry weight ± SD)	References
Microplastics found in Sediments		
Balearic Islands (W Mediterranean)	From 100.0 ± 60 to 900 ± 100	Gundogdu and Çevik, 2019
Central Adriatic Sea	From 2.5 ± 5 to 75 ± 15	Mistri et al., 2017
Northern Tunisian coast	From 141.20 ± 25.98 to 461.25 ± 29.74	Abidli et al., 2018
Aeolian Archipelago's islands, Tyrrhenian sea (NW Mediterranean)	From 151.0 ± 34.0 to 678.7 ± 345.8	Fastelli et al., 2016
Natural Park of Telascica bay (Adriatic Sea)	From 32.3 ± 20.2 to 377.8 ± 88.8	Blaskovic et al., 2017
Venice (North Adriatic Sea)	From 672 ± 124 to 2175 ± 466	Vianello et al., 2013
Grand Harbour of Malta (Central Mediterranean)	From 4 to 12	Romeo et al., 2015
Maremma Regional Park (Tyrrhenian Sea, Italy)	From 45 to 1069	Guerranti et al., 2017
Ebro Delta (NW Mediterranean)	422 ± 119	Simon-Sanchez et al., 2019
Countries from where samples were collected	**Average litter density (items/m^2)**	**References**
Microplastics found in Beaches		
Italy	1.06	Giovacchini et al., 2018
Spain	0.116	Asensio-Montesinos et al., 2019
Morocco	0.054	Nachite et al., 2019
Greece	0.24	Vlachogianni et al., 2018
Croatia	2.9	Vlachogianni et al., 2018
Slovenia	1.5	Laglbauer et al., 2014
Montenegro	0.37	Vlachogianni et al., 2018
Albania	0.22	Vlachogianni et al., 2018

organisms (other than bacteria and fungi) have been detected on maritime plastics which include algae, sponges, mollusks, and crustaceans. Illuminating the role of this plastic litter in the microbial loop, particularly in ocean gyres will help us to understand the environmental impact of this pollution on ocean ecosystems as plastic debris will offer a surface for microorganisms where all the limiting nutrients are sufficient for the survival of these organisms (Mincer et al., 2016). Apart from that, the microorganisms can biotransform plastic litter into harmful compounds which could pose a great threat to food security and also to human health (McCormick et al., 2011).

In the Mediterranean Sea presence of plastisphere is also evident and a huge number of microorganisms were isolated from the plastic debris. An organization *viz.*, "The Expedition MED" which consists of a team of scientists, volunteers, and oceanographers organizes many events since 2017 to work on this concept of plastisphere in the Mediterranean Sea. This organization aims to restrict the transportation of harmful chemicals into the Sea and to control the pathogenic microorganisms before they enter the food chain (Alessi and Carlo, 2018).

The study of plastisphere not only needed high-throughput technology but also required proper expertise to handle the microorganisms. Earlier studies of the plastisphere (for identification of microorganisms) were primarily based on the principle of microscopy (Sieburth, 1975), but nowadays, modern molecular techniques such as high-throughput DNA sequencing are gaining attention to study the plastisphere (De Tender et al., 2017). It was investigated by DNA sequencing experiment that in the plastisphere microorganisms exist in the form of natural biofilms (Kirstein et al., 2019) and significant interactions and metabolic activities were also taking place within the plastisphere (Bryant et al., 2016). In recent studies on the Mediterranean coast of Israel, DNA metabarcoding was implemented to characterize the plastisphere community isolated either from seawater or from polyethylene which was submerged for approximately 1 month in proximal different harbor sites at the Israelian Mediterranean coast. These barcodes were then sequenced using a modern Oxford Nanopore Technology and by multiplexing on a single MinION flow cell. By this analysis, a range of 1249–2141 microbial species was identified in each plastic sample comprising of both bacteria and eukaryotes. Certain plastic-degrading species were also discovered which belong to hydrocarbon-degrading strains. Besides prokaryotes, the dominance of diatoms along with algae, protists, and fungi was also noticed (Davidov et al., 2020).

The 16S rRNA profiling of the samples collected from sediments and free-floating surface water from the location of Calvi, Corsica in the Mediterranean basin showed that plastic-allied microbial biofilms of both the samples differ from each other while showing the dominance of Gammaproteobacteria and Bacteroidetes in the plastisphere. The same samples were used to examine the enrichment of plastic degrading bacteria with a range of plastics as key carbon sources (low-density polyethylene, polystyrene, and polyethylene terephthalate). It was found that certain genera of hydrocarbon-degrading bacteria, e.g., *Alcanivorax*, *Arenibacter,* and *Marinobacter* were enriched with low-density polyethylene and polyethylene terephthalate and emerged as important contenders for plastic degradation. It was also discovered in this study that *Alcanivorax borkumensis* has developed a thick biofilm on LDPE which facilitated the degradation of petroleum-based plastic (Delacuvellerie et al., 2019).

Future research on the plastisphere is highly required to protect the marine environment and human health. A combined technology with various advanced molecular and microscopic techniques has to be developed for effective isolation and identification of the plastisphere microbial community. In the coming time techniques like DNA high throughput molecular screening, DNA metabarcoding may include proteomics, transcriptomics, metagenomics, and metabolomics for the characterization of the composition of the plastisphere. Certain visualization methods such as fluorescent *in situ* hybridization can also be applied for the plastisphere study (De Tender et al., 2017).

EFFECT OF MICROPLASTIC POLLUTION ON THE MARINE ANIMALS INHABITING THE MEDITERRANEAN SEA

In recent time's biodiversity loss due to marine pollution is a concerning threat to marine ecology and sea health. Plastic litter is one of the evildoers responsible for the loss of biodiversity in seas and oceans around the globe (STAP, 2012), and the Mediterranean Sea is not an exception. The ingestion of toxic microplastic fragments by aquatic biota is one of the main reasons for the loss of marine lives and over 800 marine species were contaminated with plastic litter either via ingestion or entanglement (Dias B. F. S., 2016). Microplastic ingestion has been reported in marine fishes and seabirds but studies are limited in the case of invertebrates due to its demand for advanced technologies and time constraint issues (Dias B. F. S., 2016). In another study, over 220 marine species have been reported to ingest microplastics in which 55% species were of commercial importance that includes mussels, shrimps, oysters, Norway lobster, anchovies, Atlantic herring, Atlantic cod, common carp, and Acoupa weakfish (Lusher et al., 2017). A research carried out by Fossi et al. (2018), concluded that Seabirds were highly impacted by the ingestion of microplastics over the last two decades. Approximately 60% of cetacean species were also documented for the ingestion of microplastics. Both cetaceans and seabirds were exposed to microplastics due to their higher position in the food web and also because of their conspicuous nature. In a study, the cetaceans of the Mediterranean Sea and seabirds of eastern Australia were opted as two case studies to diagnose the toxicological stress against debris-associated pressures. The exposed marine biota has negative and toxic effects which include diminishing reproduction behavior as well as lowering of survival rates (Fossi et al., 2018). The plastic particles also act as a vector for toxic hydrophobic chemicals in the seawater as these pollutants get adsorbed onto the surface of the plastic and ultimately transfer across the food chain (Teuten et al., 2007; Tanaka et al., 2013). In the Mediterranean Sea, microplastics have been detected in various species, such as invertebrates, mussels, sea birds, and fish (Piccardo et al., 2018; Mancia et al., 2020). The interaction of marine biota with plastic fragments results in entanglement and ingestion which may result in toxicity, endocrine disruption, carcinogenicity, and other physical injuries such as blockage and internal abrasion (Wright et al., 2013).

Entanglement

In the world's Seas and Oceans, the entanglement of marine animals due to plastic debris has posed an adverse impact on the marine organisms as it leads to wounds that hinder an organism's capability to move, feed, reproduce, and potentially could cause death due to suffocation, starvation, and strangulation (Kuhn et al., 2015). Entanglement also leads to cause scratches and infections which might result in altered behavior and hampering their rate of survival (Katsanevakis, 2008). In the Mediterranean basin, the first report of entanglement of the marine animal was documented in 1979 when a small marine turtle was entangled with a plastic sheet around its shell in the Eastern Mediterranean Sea (Morris, 1980). It is also reported that *Caretta caretta,* a prominent species of the loggerhead sea turtle in the Mediterranean Sea is the most affected animal due to entanglement. The species of *Caretta* faced high impact from plastic sheets and bags (originated from land-sources), and also from fishing lines and fishing aggregating devices (originated from marine-sources) as the sea turtles in the juvenile phase are very much reliant on the drift lines for food and shelter (Katsanevakis, 2008). The ocean currents forming drift lines are transporting hatchlings toward convergence zones of the oceans, and tend to concentrate suspended anthropogenic debris which results in the trapping of juvenile turtles either through entrapment or ingestion, or entanglement (Duncan et al., 2017). A report published in 2018 related to a study conducted on the Samandag beach (Turkey) has mentioned that the entanglement of *Chelonia mydas* (green turtles) in plastic net ropes or bags was the main reason for the death of these turtles as the presence of plastic fragments was also found in the digestive system of this animal (Sonmez, 2018). This is an issue of concern as *C. mydas* is one of the endangered marine species and their population is declining rapidly due to this plastic pollution and also because of the extensive fishing practices, and exploitation of hatched eggs and adult female progeny at beaches. The impact of entrapment of plastic gears on *Monachus monachus* (Mediterranean monk seal) was also reported in the Mediterranean basin, and it was found that the species suffered entanglement in the floating fishing gears and plastic hoops in different habitats such as the Western Mediterranean Sea, the Central Mediterranean Sea, the Aegean-Levantine Sea and the Ionian Sea (Karamanlidis et al., 2008). The entrapment in fishing gears was also reported for *Physeter macrocephalus* (sperm whale) in the Southern Tyrrhenian Sea (Pace et al., 2008), for *Tursiops truncates* (bottlenose dolphin) in the Adriatic Sea (Gomercic et al., 2009), and for *Grampus griseus* (Risso's dolphin) in the Greek Seas (Frantzis, 2007).

Apart from that, this plastic litter also acts as a considerable stressor for coral reefs in the Mediterranean Sea leading to shading suffocation and mortality of coral reefs (Galgani et al., 2018). Approximately nineteen Cnidarian species were subjected to entrapment in the sub-regions of the Ionian Sea and Western Mediterranean Sea. The entrapment of *Paramuricea clavata* was found in the sub-region of the Adriatic Sea and *Dendrophyllia ramea* in the sub-region of the Aegean-Levantine Sea. A few reports on crustaceans (*Maja squinado* and *Geryon trispinosus*), mollusks (*Sepia officinalis)*, and echinoderm (*Cidaris cidaris)* have also been published which showed their sufferings due to entanglement in fishing nets in the Mediterranean Sea.

Ingestion

Apart from the entanglement problem, plastic ingestion is another serious issue in the contaminated marine environment as it harms the health of the marine organisms (Anastasopoulou and Fortibuoni, 2019). Plastic fragments have been detected in all trophic levels ranging from planktonic species to invertebrates (bivalves and polychetes), and vertebrates (fish, sea birds, and mammals) (Derraik, 2002; Cole et al., 2013; Wright et al., 2013). The process of ingestion may be intentional or accidental through passive predation or by filter-feeding activity. In the marine ecosystem, filter-feeding organisms ingest these microplastics by filtering the huge water volumes they are associated with (Llorca et al., 2020). In the Mediterranean Sea, the existence of microplastics has been observed in different species of invertebrates, crustaceans, mussels, and fishes (Mancia et al., 2020). Among these, mussels are of significant interest because of their filter-feeding activities. There are shreds of evidence that suggest, mussels consume smaller microplastic particles, and translocation of these tiny microplastics occurs from the digestive system of the mussels to the gills part (Qu et al., 2018). The experimental analysis showed that when Mediterranean based mussel *Mytilus galloprovincialis* get exposed to polystyrene spheres under controlled parameters, these animals were able to filter microplastics and after ingestion, these tiny plastic fragments were traveled to the gut cavity and then passed through feces without committing any histo-pathological harm in the body (Gonçalves et al., 2019). The ingested microplastics in *M. galloprovincialis* were examined in seawater of the Northern Ionian Sea and it was found that polyethylene polymer was the most abundant one in the gut tissue. The ingestion of microplastics by Mediterranean mussels has raised an alarm as these mussels are sold for human consumption and can cause serious impacts on human health (Digka et al., 2018). The microplastics were detected in crustaceans specifically in Leptostraca, amphipods, and decapods, and plastic litter was also recorded in one Leptostraca, four decapods, and four amphipod species in the Western Mediterranean Sea (Anastasopoulou and Fortibuoni, 2019).

Plastic ingestion has also been recorded in approximately 69 species of fish and the most affected were demersal (30.4%), pelagic (15.9%), benthopelagic (24.6%), bathypelagic (11.6%), and bathydemersal (5.8%). The demersal species are utilized for human consumption and thus of economic importance. Among all the demersal species, the ingestion of microplastics by *Solea solea* was very frequent in the Adriatic Sea (95%), and this is why the microplastic particles were detected in their gastrointestinal cavity (Pellini et al., 2018). The percentage range of microplastic ingestion by demersal *Mullus surmuletus* was between 27% in the Western Mediterranean Sea (Anastasopoulou et al., 2018) and 70% in the Adriatic Sea (Alomar et al., 2017). The traces of microplastics were also found in the gut cavity of *Merluccius merluccius*, a fish species habitat to the Mediterranean basin (Giani et al., 2019; Mancuso et al., 2019). The pelagic species *Sardina pilchardus* exhibited the presence of plastic fragments in their gut cavity with the highest frequency of 96% reported in the Adriatic Sea (Renzi et al., 2019). In the North Pacific zone, a higher percentage of ingested microplastics (91%) were detected in pelagic *Engraulis encrasicolus* (Davison and Asch, 2011). In the case of benthopelagic species like *Pagellus erythrinus* about 2% of macro-plastic ingestion was reported in the Central Mediterranean Sea and 3.3% ingestion was evident in the Adriatic Sea (Anastasopoulou et al., 2018). Other benthopelagic species such as *Spondyliosoma cantharus* and *Phycis phycis* in the Tyrrhenian Sea have also been reported with high levels of microplastics in their stomachs (Avio et al., 2017). The concentration of microplastics in bathypelagic species varied from 0.3 to 11.8%, where the lowest concentration of plastic fragments (0.3%) was detected in *Diaphus metopoclampus,* and the highest concentration (11.8%) was observed in *Notacanthus bonaparte* (Romeo et al., 2016; Romeu et al., 2016). The bathydemersal species inhabiting the waters of the Western Mediterranean Sea was evaluated for microplastics contamination and approximately 33.3% of *Trachyrincus scabrous* was reported which contain microplastic particles in their digestive system (Cartes et al., 2016). This *Trachyrincus* species often prey upon smaller fishes and thus the uptake of microplastics is due to a secondary ingestion pathway. In other bathydemersal species like *Polyacanthonotus rissoanus* thin plastic threads were detected in specimens recovered from the Western Mediterranean Sea (Romeu et al., 2016), and plastic ingestion was also reported in this region for the two species, e.g., *Helicolenus dactylopterus* and *Glossanodon leioglossus* (Compa et al., 2019).

In the Mediterranean Sea, the plastic ingestion by different marine mammals is less evaluated in comparison to other marine organisms such as mussels, fish, sea turtles, and marine birds (Alexiadou et al., 2019) although several cases have been reported worldwide (De Stephanis et al., 2013). Much of the interactions between bulky marine mammals and plastic litter are more related to entanglement than ingestion (De Stephanis et al., 2013). Till now, dolphins have been detected to ingest marine plastic litter and this was proved in the case of *Grampus griseus* (Risso's dolphin) where the ingestion of higher concentration of plastic fragments was documented along the subregion of Aegean- Levantine (Mediterranean coast of Israel) (Shoham-Frider et al., 2002). In addition to that, ingestion of fragments of nylon nets was reported in the case of *Tursiops truncates* (bottlenose dolphin) in the Port of Haifa, Israel (Levy et al., 2009). It has been observed that in specimens of dolphins of the Mediterranean Sea, almost 10% had different pieces of gill nets in their respective fore-stomach and esophageal cavities resulting in heavy ulcerations. This is because dolphins could tear off parts of gill nets during their feeding on small fish entangled in fishing gears (Gomercic et al., 2009). In an important study in the North Sea, plastic ingestion was also reported in *Phocoena phocoena* (harbor porpoise) (Van Franeker et al., 2018).

With the rise in plastic debris in the seas and oceans, these marine species in long run are going to be endangered and get extinct 1 day. Loss of species in the marine environment has already created an imbalance in the marine ecosystem and the Mediterranean Sea is one of the worst sufferers. An overall representation of the Mediterranean Microplastic pollution is shown in **Figure 1** depicting all the points discussed above.

VARIOUS POLICIES IMPLEMENTED TO RESTRICT MICROPLASTIC POLLUTION IN THE MEDITERRANEAN REGION

The toxic and harmful effects of microplastics on the environment have resulted in the formulation of different policies for the immediate restriction of its use and also for proper management of plastic debris. For this, various collaborations at local, national, and international levels are needed on an emergency basis (Alessi and Carlo, 2018). Fortunately in the Mediterranean region, different campaigns and legislative policies have been formulated to reduce the problem of plastic pollution in the marine ecosystem of the Mediterranean basin. The United Nations Environment Organization has recently launched a campaign for the elimination of primary sources of plastic litter which includes microplastics in cosmetics and also banning the handling of single-use plastic by the end of 2022. In Europe, different legislative policies have been formulated for all the Member States to monitor microplastic pollution (Li et al., 2018). An important environmental initiative has been promoted through the program *Horizon 2020* whose aim is to reduce the plastic from the ecosystem (Gago et al., 2018). In October 2020, the European Parliament has initiated the proposal to prohibit single-use plastics from the year 2021. Following are the policies adopted and implemented by different Mediterranean countries related to the reduction of environmental plastic pollution.

France

In 2016, France has approved a 4 years plan for a complete ban of single-use plastics. The ban on plastic bags was also initiated along with the complete ban on plastic packaging products by the end of 2020 (Bayo et al., 2018). France has also formulated a model to achieve 100% recycling of plastics by the end of 2025. Additional legislative policies will also be implemented for the proper management of plastic waste (Alessi and Carlo, 2018).

Greece

The first environmental law was implemented in the country in 2018 for the restriction of plastic bags. A tax of about 4 cents per plastic bag was imposed and in 2019 the tax increased to 7 cents per plastic bag (Bayo et al., 2018). This measure has reduced the usage of single-use plastic bags (∼80–85%) in recent years (Ekathimerini, 2020). In addition to that, the National Solid Waste Strategy and National Strategic Solid Waste Prevention Programme were formulated which was aimed to recycle 70% plastic materials by 2020 (Alessi and Carlo, 2018).

Italy

In August 2017, plastic bags were completely banned for commercial practices, and also in compliance with the European Union directive, a fine of approximately 1–3 cents per plastic bag was imposed. In the Italian territory of the Tremiti archipelago, the government had approved a law in 2016 regarding the ban on disposable plastics, and even a fine of € 500 was contemplated for the violation of the law (Bayo et al., 2018). Also in January 2020, the use of microbeads and microplastic in cosmetic and other domestic products were completely restricted (Alessi and Carlo, 2018).

Egypt

On World Environment Day (5th June), 2017 the National Initiative on Reduction of Plastic Bags Consumption was launched by the Ministry of Environment, Egypt. This program was in partnership with the United Nations Environment and Center for Environment and Development for the Arab Regions and Europe and funded by the European Commission. This initiative was aimed to restrict the utilization of plastic bags at the commercial level, formulate policies for the reduction of single-use plastics, and encourage people to opt for eco-friendly alternatives (SGP Report, 2017). This policy has also covered the scope for the reduction of high-density polyethylene plastic bags of thickness up to 50 microns which are frequently used in the market for shopping and other household purposes. Different consultation workshops were also organized for the retailers, plastic manufacturers, and the common people to spread awareness against the use of plastic and related pollution originated from plastic litters (Bayo et al., 2018).

Croatia

The country has adopted special legislative policies such as the Marine and Coastal Management Strategy to address the problem of marine litter in Croatia. This policy aims at the protection, preservation, rehabilitation, and restoration of marine and coastal ecosystems. It will also work toward the maintenance of different human activities in the coastal area and sea. This policy in long run will help in the reduction of plastic pollution, and preserve protected areas (Kuzmanovic and Napa, 2019). Different policies have been formulated for food-based industries related to packaging which can be recycled and reused. The plastic waste management system in the country has been improved phase-wise, and by 2022 Croatia has set targets for a well-established marine waste management system (Alessi and Carlo, 2018).

Spain

In 2018, The Royal Decree 293/2018 was published to adopt different measures for the reduction of consumption of plastic bags and to prevent the environment from adverse impacts of plastics by restricting plastic bags dispersion in the environment (NVC News, 2018).

In the Mediterranean basin, different voluntary projects have also been formulated in association with different NGOs and plastic manufacturers association to control the accumulation of plastic litter in the environment and to save the Mediterranean ecosystem from the plastic menace. A voluntary commitment to Plastic 2030 was developed by Plastics Europe with an ambition to attain a fully circular economy, often called "New Plastics Economy." The key objectives of this initiative are to increase reuse and recycling with a target of 60% for plastic packaging by 2030. This will also help to achieve the objective of 100% recycling and reuse of plastic packaging by 2040 (PlasticsEurope, 2018). The *ACT4LITTER* project has been initiated in the Mediterranean basin for effective handling of marine litter deposited in the sea, and different preventive measures have also been taken for the conservation of Mediterranean Marine Protected Areas (MPAs) (ACT4LITTER, 2017). A voluntary adherence Project, "Operation Clean Sweep" was formulated with a commitment to the plastic manufacturers to implant different control measures to avoid the release of plastic pellets in the environment. The Spanish Association of Plastic Industries (ANAIP) was also formed which promotes various collaborative forums required for the market to enhance the competitiveness among the plastic recycling industrial sectors and also for promoting its adequate usage for the improvement of quality of planet by reducing plastic concentration (Bayo et al., 2018). In July 2018, an air over-flight operation of waters of the Mediterranean Sea was launched. This initiative in long run will provide an in-depth evaluation of the abundance, density, and distribution of marine biota in the Mediterranean Sea (Bayo et al., 2018).

FUTURE DIRECTIONS AND WAY FORWARD

Urgent actions are needed by the industrial sectors that are operating in the Mediterranean basin, and a complete zero waste policy has to be taken to stop single-use plastic product usage. Industries should redesign the infrastructure for all production processes that allow the utilization of recycled plastic and all the eco-friendly alternatives. The most urgent need is that the tourism industry should restrict the utilization of all single-use plastic articles (bags, straws, bottles, caps) and must encourage the use of biodegradable resources. To assess the impact of microplastics on aquatic ecosystems and sea health, proper assessment should be done on the entrance of these harmful pollutants in the food web through different sources. Close monitoring is required in all the water-channels to prevent microplastic entry into the Seas and Oceans. For this, proper marine waste management systems should be constructed in all the neighboring countries. Nearly 80% of microplastic pollution in the Mediterranean Sea is based on land sources and therefore effective and feasible Legislative policies for the countries surrounding the Mediterranean basin should be framed to limit plastic distribution and to eliminate plastic pollution. Many species inhabiting the Mediterranean Sea have been adversely impacted already and therefore to save the Mediterranean ecosystem, strict laws should be implemented to control plastic littering. More scientific research on this area and creating awareness among the people living in this region are the priority at this moment.

CONCLUSION

The hazardous effect of plastic pollution is causing serious impacts on the economic sectors in the Mediterranean basin, specifically in the tourism and fisheries sectors. The estimated loss due to this marine litter is € 61.7 million every year which is due to the reduction in seafood demand regarding the concern on the quality of fish and other seafood items. Plastic polluted beaches are discouraging tourism and hampering the livelihood of people of the Mediterranean region. This loss can be understood by considering the example of Nice (a French town of the North Mediterranean basin) which spends approximately € 2 million each year on beach cleaning. Apart from economic loss, environmental and human health risks associated with microplastics and their bound toxic co-contaminants and pathogenic microorganisms are also a great concern.

The risks coming from the chemicals associated with microplastics are difficult to illustrate because very few research studies have been done so far globally on this topic. The toxicity of these chemicals also depends on shape and size and thus detailed research is required to characterize these compounds. In addition to that, the increased bioaccumulation potential of these chemicals has laid toxicological effects on the marine environment and also on human health through the food chain. Therefore, the identification of these toxic additives is very crucial, and advanced molecular techniques must be employed to solve this issue. The concern of the plastisphere is also very alarming in the Mediterranean Sea as biotransformation and modification of plastic debris by co-contaminants and microorganisms posed a great threat to the marine biota and thus this problem demands immediate actions. The multi-omics technology may play an important part in this regard by decoding the pathways of such biotransformations and modifications.

AUTHOR CONTRIBUTIONS

SS: writing – review, editing, and data curation. VS: writing – review and editing. SC: conceptualization, writing – review, editing, and overall supervision of the work. All authors contributed to the article and approved the submitted version.

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