Poly(Ethylene Terephthalate) Microplastics

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The high PET production volume and the waste mismanagement of PET litter make it one of the most polluting plastic material. Its diffusion in marine litter is widely assessed according to public opinion and documented in the literature. The major sources of PET microplastics in the marine environment are bottles and fibers. The role of PET micro/nanoplastics of vector of toxic chemicals, their fate and the negative effects on the environment and human health is still under discussion.

marine litter | ocean pollution | microplastics | model nanoplastics | adsorption | kinetics | PET | organic contaminants | release | degradation | transport phenomena

1. Introduction

Currently, the massive population expansion and the daily use of polymers for producing and consuming non-reusable objects for different applications (packaging, cosmetics, textiles, detergents, greenhouses, mulches, fishing nets, coating and wiring, trays and bottles, covers, bags, and containers) cause wild waste accumulation, with consequent significant complications owing to its management and disposal [1][2][3][4]. In specific, the municipal solid waste worldly production passed from 1.3 billions of tons in 1990 to 3.81 billions tons after 25 years [5][6]. Even if the waste flow comes from different sources [7][8], plastics represent a substantial portion of the municipal solid waste. In 2016, about 27.1 million metric tons (Mt) of plastic litters were stored in the European Union (EU), of which 31.1%, 41.6%, and 27.3%, were recycled, reused (for energy production), and dumped again in landfill sites, respectively [9]. Among polymer materials, the greatest contribution is provided by thermoplastic polymers, whose consumption (about 80% of all synthetic polymers) is mostly attributable to packaging and containers, as well as the production of textile fibers [10]. Hence, plastics can be considered highly responsible for waste management issues, not only because of their extensive usage but also because of their short service life together with their long (bio)degradation time [11].

In addition, a great universal worry is due to the plastics' storage in landfills because of their easy accessibility in the environment. In particular, mismanaged plastic waste of polyethylene containers and Poly(Ethylene terephthalate) bottles of beverages, the most common polymers found in urban waste, leads to a huge amount of surface water and seabed marine litter [12].

Poly(Ethylene terephthalate), generally labeled as PET, is a thermoplastic polymer of the polyesters family produced by the reaction of ethylene glycol and terephthalic acid under high temperatures and low vacuum pressure. The resulting polyester polymer is characterized by high strength and stiffness, low density, good creep behavior, high chemical resistance, and low cost [13].

Today, PET is one of the world's most commonly used and versatile materials. Global Poly(Ethylene terephthalate) production was 30.3 million tons in 2017 [14], while European PET demand was about 4 million tons in 2018, as compared to the global plastics production of nearly 360 million tons [9]. It is used for bottles, food containers, and synthetic fiber production. It is forecasted that 583 billion PET bottles will be produced in 2021 [15], and for this reason it could be considered one of the most responsible polymers in marine pollution [2]. PET is used not only in the food packaging and textile fields but also in agriculture, electrical applications, and several composite applications in combination with reinforcement fibers for various industrial and civil engineering applications that typically require higher strength and/or higher heat resistance [16][17][18]. Recently, the interest in fiber-reinforced PET has increased due to its benefits, as compared with thermoset composites, such as damage tolerance, high impact resistance, chemical and solvent resistance, unlimited shelf life, low storage costs, welding ability, and recyclability [19][20][21].

Plastic pollution in the marine environment has recently been recognized as one of the most impacting threats for the environment, causing numerous hazardous and ecologically negative consequences, such as the entanglement of the marine species within the plastic or their ingestion [22][23]. In particular, juvenile fish, reptiles (i.e., turtles, etc.), and mammals often become entangled in plastic waste with consequent severe damage for the animal growth [24][25] and restriction of movement precluding them from correctly feeding and, in the case of mammals, breathing [26][27]. A wide variety of species have been reported to be harmfully crushed by plastic trash, such as for example marine birds [28][29], sea turtles [30], cetaceans [31], fur seals [24], sharks [25], and filter feeders [32]. Marine birds are very prone to the ingestion of plastic objects that they mistake for food [28][29]. Plastic ingested by these marine organisms remains in the digestive tract and can lead to reduced feeding stimuli, gastrointestinal obstruction, decreased secretion of gastric enzymes, and lower levels of steroid hormones, causing reproduction difficulties [5]. Specific classes of litter found in the oceans, involving the Antarctic [33], have been observed in the sea for at least four decades [34][35][36].

Microplastics (MPs) are generally defined as polymer particles with a regular or irregular shape and a size ranging between 5 mm and 1 µm and are insoluble in water [37], while bigger particles, such as pellets, are called mesoplastics [26][38][39]. However, a clear and accepted terminology and classification is still under discussion, as well as a standardization of the plastic collection and analysis methods [40]. Microfibers (MFs), very fine fibres (approx. 3–10 µm in diameter), spun as endless filaments can be of both synthetic and natural origin. The size to diameter ratio is also quite high, on the order of 10^3, which is an additional crucial property of MFs [41]. The most common constituents of MPs include polyethylene (PE), polystyrene (PS), polyethylene terephthalate (PET), polyvinylchloride (PVC), and polypropylene (PP), [34][42][43]. MPs generally arise from the plastic pollution of seaside and beaches, deriving from fragmentation phenomena or from powders employed, for example, in cosmetics [44][45]. Both microplastic and mesoplastic litters can be eaten by marine species and, thus, can reach the marine food network. In contrast to macroscopic plastic litters, MPs on the seaside, seabed, or surface water, frequently combined with sand, are complicated to be stored and, at present, there is not an easy and universal method for the calculation of their amount [46]. Furthermore, the degradation of marine MPs due to prolonged external light exposure, mechanical abrasion, and biodegradation can cause the creation of nanoplastics (NPs) with sizes lower than 1 μm [47][48][49][50][51]. In particular, marine MPs were investigated by several researchers, and their presence has widely been proven in coastal environments [52][53][54]. The freshwater system is also considered a potential sink of MPs [55][56][57][58][59]. Zbyszewski and Corcoran [60] reported for the first time the presence of MPs in the freshwater system during the coastline of Lake Huron, Canada. Very recently, Li et al. [61] evidenced that there are different concentrations of MPs in Australia, Asia, North America, and Europe. The current literature underlines that MPs are found in every sea basin around the world, with higher concentrations occurring in intense human activity areas demonstrating that plastic debris transport can be extremely efficient and that the prediction of the plastics' fate is of paramount importance [62]. Additionally, the study and modeling of the transport of MPs in the marine environment has attracting increasing interest [63]. MPs have been detected also in urban atmospheres as well as in remote and pristine environments, showing that atmospheric transport of MPs is also very significant [64][65].

2. Poly(Ethylene Terephthalate) Microplastics

Despite PET representing 10% of plastic production, its diffusion in marine litter is widely assessed according to public opinion and documented in the literature. The major sources of PET microplastics in the marine environment are bottles and fibers. Bottled water is one sector of the beverage industry that has recently experienced substantial growth, and the consumption of plastic bottles is expected to increase by 20% by 2021 [66]. It is estimated that 500 billion plastic bottles are used every year, but less than half are recycled [67]. Unfortunately, due to waste mismanagement and illegal dumping, PET bottles are highly present in the marine litter, despite PET being more widely recycled than other polymers. According to the report of Ocean Conservancy International Coastal Cleanup [68], plastic bottles are the third most littered item collected in 2019 around the world. Several beach litter surveys highlight the presence of PET bottles in coastal pollution, with different percentages depending on the climatic period, tourism exploitation, disposal regulation, etc. [69][70]. For instance, according to Simeonova and Chuturkova [71], plastic drink bottles represent by weight about 44% of the Bulgarian Black Sea coastal pollution. Brouwer et al. [72] performed social research in European countries bordering the Mediterranean Sea, Black Sea, and the North Sea. They reported that after cigarette butts, the most frequently recorded litter type by beach visitors is plastic bottles.

Waste with a density higher than that of seawater sinks to the bottom of the sea. For this reason, PET bottles are abundant among deep-sea litter items, as reported for different geographical places, for example in the Caribbean Sea [73], the Mediterranean Sea [74][75], the East China Sea [76], etc. However, PET bottles with closed caps can float and make a long journey, as demonstrated by Duncan et al. [77], who released PET bottles, equipped with GPS and satellite tags, into the Ganges River and the Bay of Bengal. Carried by coastal currents, the bottles released into the ocean travelled long distances of up to 2845 km in 94 days before being dispersed. This demonstrates that plastic pollution is a truly global issue, as a plastic bottle dropped in a river or ocean can travel thousands of miles in a few months.

Recently, PET fibers, which account for 70% of all synthetic fibers [78] with a global consumption of about 50 Mton/year [79], have been recognized as an emerging source of pollution. They are released in relatively large amounts in wastewaters of common laundry cycles and escape removal from wastewaters in treatment plants due to the very low dimensions (diameters in the 10–20 µm range and masses between 1.7 and 7.0 µg) [79]. PET fibers can generate microfibers through fragmentation and degradation. After entering freshwater and seawater, they may be transported by currents and turbulent hydrodynamic conditions before sinking in the water column [36] and ending up in marine sediments, where they can be ingested by aquatic organisms [80]. Geyer et al. [81] estimated that 5.6 Mt of synthetic microfibers were emitted from apparel washing between 1950 and 2016. Half of this amount was emitted during the last decade, with a compound annual growth rate of 12.9%.Despite PET being more widely recycled than other polymers, the recycling volume is quite different across countries depending on their policies. There are still several countries where PET recycling is low. Moreover, even if PET is recycled, illegal dumping in the sea is a big problem; additionally, a bottle made of recycled PET can be illegally dumped in the ocean, making all recycling efforts useless. Therefore, the high volume of production of PET and waste mismanagement make PET one of the most polluting plastic materials. The abundance of PET microplastics and their continuous degradation in the marine environment to nanoplastics have raised concerns due to their entering the food chain through multiple routes, increased bioavailability, their impact on low-trophic organisms through the uptake of toxic chemicals, and the increased risks for human health [82]. The issues related to PET MPs/NPs have been less studied than those related to more abundant polymers such as polyethylene (PE) or polystyrene (PS), but interest in research on this topic has been greatly increasing in the last three years, as proved by the very recent literature.

References

1. Ferrari, F.; Striani, R.; Minosi, S.; De Fazio, R.; Visconti, P.; Patrono, L.; Catarinucci, L.; Corcione, C.E.; Greco, A. An innovative IoT-oriented prototype platform for the management and valorisation of the organic fraction of municipal solid waste. J. Clean. Prod. 2020, 247, 119618.
2. Ferrari, F.; Esposito Corcione, C.; Montagna, F.; Maffezzoli, A. 3D Printing of Polymer Waste for Improving People's Awareness about Marine Litter. Polymers 2020, 12, 1738.
3. Al-Salem, S.M.; Lettieri, P.; Baeyens, J. Recycling and recovery routes of plastic solid waste (PSW): A review. Waste Manag. 2009, 29, 2625–2643.
4. Valdés, A.; Mellinas, A.C.; Ramos, M.; Garrigós, M.C.; Jiménez, A. Natural additives and agricultural wastes in biopolymer formulations for food packaging. Front. Chem. 2014, 2, 6.
5. Beede, D.N.; Bloom, D.E. Economics of the Generation and Management of MSW; National Bureau of Economic Research Working Paper Series; National Bureau of Economic Research: Cambridge, MA, USA, 1995; Working Paper 5116.
6. Ritchie, H.; Roser, M. Plastic Pollution. Available online: (accessed on 18 March 2021).

7. Esposito Corcione, C.; Ferrari, F.; Striani, R.; Visconti, P.; Greco, A. An innovative green process for the stabilization and valorization of organic fraction of municipal solid waste (OFMSW): Optimization of the curing process II part. Appl. Sci. 2019, 9, 3702.
8. Ferrari, F.; Striani, R.; Visconti, P.; Esposito Corcione, C.; Greco, A. Durability analysis of formaldehyde/solid urban waste blends. Polymers 2019, 11, 1838.
9. Plastics—The Facts 2019. Available online: (accessed on 5 December 2020).
10. Dewil, R.; Everaert, K.; Baeyens, J. The European plastic waste issue: Trends and toppers in its sustainable re-use. In Proceedings of the 17th International Congress of Chemical and Process Engineering, Prague, Czech Republic, 27–31 August 2006; pp. 27–31.
11. Issifu, I.; Sumaila, U.R. A Review of the Production, Recycling and Management of Marine Plastic Pollution. J. Mar. Sci. Eng. 2020, 8, 945.
12. Verma, R.; Vinoda, K.S.; Papireddy, M.; Gowda, A.N.S. Toxic pollutants from plastic waste—a review. Procedia Environ. Sci. 2016, 35, 701–708.
13. Bjorksten, J. Polyesters and Their Applications; Reinhold Publishing Corporation: New York, NY, USA, 1956.
14. Polyethylene Terephthalate (PET): Production, Price, Market and Its Properties. Available online: (accessed on 7 April 2021).
15. Tiseo, I. Global PET Bottle Production 2004–2021. Available online: (accessed on 28 March 2021).
16. Dell’Anna, R.; Lionetto, F.; Montagna, F.; Maffezzoli, A. Lay-up and consolidation of a composite pipe by in situ ultrasonicwelding of a thermoplastic matrix composite tape. Materials 2018, 11, 786.
17. Greco, A.; Lionetto, F.; Maffezzoli, A. Processing and characterization of amorphous polyethylene terephthalate fibers for the alignment of carbon nanofillers in thermosetting resins. Polym. Compos. 2015, 36, 1096–1103.
18. Cascardi, A.; Dell’Anna, R.; Micelli, F.; Lionetto, F.; Aiello, M.A.; Maffezzoli, A. Reversible techniques for FRP-confinement of masonry columns. Constr. Build. Mater. 2019, 225, 415–428.
19. Lionetto, F.; Pappadà, S.; Buccoliero, G.; Maffezzoli, A. Finite element modeling of continuous induction welding of thermoplastic matrix composites. Mater. Des. 2017, 120, 212–221.
20. Lionetto, F.; Moscatello, A.; Totaro, G.; Raffone, M.; Maffezzoli, A. Experimental and numerical study of vacuum resin infusion of stiffened carbon fiber reinforced panels. Materials 2020, 13, 4800.

21. Lionetto, F.; Montagna, F.; Maffezzoli, A. Out-of-Plane Permeability Evaluation of Carbon Fiber Preforms by Ultrasonic Wave Propagation. Materials 2020, 13, 2684.
22. Webb, H.K.; Arnott, J.; Crawford, R.J.; Ivanova, E.P. Plastic degradation and its environmental implications with special reference to Poly(Ethylene terephthalate). Polymers 2013, 5, 1–18.
23. Derraik, J.G.B. The pollution of the marine environment by plastic debris: A review. Mar. Pollut. Bull. 2002, 44, 842–852.
24. Pemberton, D.; Brothers, N.P.; Kirkwood, R. Entanglement of Australian fur seals in man-made debris in Tasmanian waters. Wildl. Res. 1992, 19, 151–159.
25. Sazima, I.; Gadig, O.B.F.; Namora, R.C.; Motta, F.S. Plastic debris collars on juvenile carcharhinid sharks (Rhizoprionodon lalandii) in southwest Atlantic. Mar. Pollut. Bull. 2002, 44, 1149–1151.
26. Gregory, M.R.; Andrady, A.L. Plastics in the marine environment. Plast. Environ. 2003, 379–401.
27. Gregory, M.R. Environmental implications of plastic debris in marine settings—Entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos. Trans. R. Soc. B Biol. Sci. 2009, 364, 2013–2025.
28. Azzarello, M.Y.; Van Vleet, E.S. Marine birds and plastic pollution. Mar. Ecol. Prog. Ser. 1987, 37, 295–303.
29. Blight, L.K.; Burger, A.E. Occurrence of plastic particles in seabirds from the eastern North Pacific. Mar. Pollut. Bull. 1997, 34, 323–325.
30. Barreiros, J.P.; Barcelos, J. Plastic ingestion by a leatherback turtle Dermochelys coriacea from the Azores (NE Atlantic). Mar. Pollut. Bull. 2001, 42, 1196–1197.
31. Baird, R.W.; Hooker, S.K. Ingestion of plastic and unusual prey by a juvenile harbour porpoise. Can. J. Fish. Aquat. Sci. 2000, 51, 172–178.
32. Moore, C.J.; Moore, S.L.; Leecaster, M.K.; Weisberg, S.B. A comparison of plastic and plankton in the North Pacific central gyre. Mar. Pollut. Bull. 2001, 42, 1297–1300.
33. Zarfl, C.; Matthies, M. Are marine plastic particles transport vectors for organic pollutants to the Arctic? Mar. Pollut. Bull. 2010, 60, 1810–1814.
34. Horton, A.A.; Dixon, S.J. Microplastics: An introduction to environmental transport processes. Wiley Interdiscip. Rev. Water 2018, 5, e1268.
35. Barnes, D.K.A.; Galgani, F.; Thompson, R.C.; Barlaz, M. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. B Biol. Sci. 2009, 364, 1985–1998.
36. Thompson, R.C.; Olsen, Y.; Mitchell, R.P.; Davis, A.; Rowland, S.J.; John, A.W.G.; McGonigle, D.; Russell, A.E. Lost at sea: Where is all the plastic? Science 2004, 304, 838.

37. Magnusson, K.; Norén, F. Screening of Microplastic Particles in and Down-Stream a Wastewater Treatment Plant; IVL Swedish Environmental Research Institute Report; IVL Swedish Environmental Research Institute: Stockholm, Sweden, 2014.

38. Acharya, S.; Rumi, S.S.; Hu, Y.; Abidi, N. Microfibers from synthetic textiles as a major source of microplastics in the environment: A review. Text. Res. J. 2021.

39. Zilla, G.; Marc, N. Briefing Note on Microplastics Literature Review. 2020. Available online: (accessed on 16 April 2021).

40. Hartmann, N.B.; Hüffer, T.; Thompson, R.C.; Hassellöv, M.; Verschoor, A.; Daugaard, A.E.; Rist, S.; Karlsson, T.; Brennholt, N.; Cole, M. Are we speaking the same language? Recommendations for a definition and categorization framework for plastic debris. Environ. Sci. Technol. 2019, 53, 1039–1047.

41. Lares, M.; Ncibi, M.C.; Sillanpää, M.; Sillanpää, M. Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology. Water Res. 2018, 133, 236–246.

42. Bolan, N.S.; Kirkham, M.B.; Halsband, C.; Nugegoda, D.; Ok, Y.S. Particulate Plastics in Terrestrial and Aquatic Environments; CRC Press: Boca Raton, FL, USA, 2020; ISBN 1000081419.

43. Le, T.T.Y.; Grabner, D.; Nachev, M.; Peijnenburg, W.J.G.M.; Hendriks, A.J.; Sures, B. Modelling copper toxicokinetics in the zebra mussel, Dreissena polymorpha, under chronic exposures at various pH and sodium concentrations. Chemosphere 2021, 267, 129278.

44. Moore, C.J. Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environ. Res. 2008, 108, 131–139.

45. Park, J.W.; Lee, S.J.; Hwang, D.Y.; Seo, S. Recent Purification Technologies and Human Health Risk Assessment of Microplastics. Materials 2020, 13, 5196.

46. Kumar, M.; Chen, H.; Sarsaiya, S.; Qin, S.; Liu, H.; Awasthi, M.K.; Kumar, S.; Singh, L.; Zhang, Z.; Bolan, N.S. Current research trends on micro-and nano-plastics as an emerging threat to global environment: A review. J. Hazard. Mater. 2020, 409, 124967.

47. Gigault, J.; Pedrono, B.; Maxit, B.; Ter Halle, A. Marine plastic litter: The unanalyzed nano-fraction. Environ. Sci. nano 2016, 3, 346–350.

48. Frias, J.; Nash, R. Microplastics: Finding a consensus on the definition. Mar. Pollut. Bull. 2019, 138, 145–147.

49. Andrady, A.L. The plastic in microplastics: A review. Mar. Pollut. Bull. 2017, 119, 12–22.

50. De Souza Machado, A.A.; Kloas, W.; Zarfl, C.; Hempel, S.; Rillig, M.C. Microplastics as an emerging threat to terrestrial ecosystems. Glob. Chang. Biol. 2018, 24, 1405–1416.

51. Galafassi, S.; Nizzetto, L.; Volta, P. Plastic sources: A survey across scientific and grey literature for their inventory and relative contribution to microplastics pollution in natural environments, with an emphasis on surface water. Sci. Total Environ. 2019, 693, 133499.
52. Aslam, H.; Ali, T.; Mortula, M.M.; Attaelmanan, A.G. Evaluation of microplastics in beach sediments along the coast of Dubai, UAE. Mar. Pollut. Bull. 2020, 150, 110739.
53. Gallo, F.; Fossi, C.; Weber, R.; Santillo, D.; Sousa, J.; Ingram, I.; Nadal, A.; Romano, D. Marine litter plastics and microplastics and their toxic chemicals components: The need for urgent preventive measures. Environ. Sci. Eur. 2018, 30, 1–14.
54. Zhang, P.; Wei, S.-S.; Zhang, J.-B.; Ou, Z.; Yang, Y.-Q.; Wang, M.-Y. Occurrence, Composition, and Relationships in Marine Plastic Debris on the First Long Beach Adjacent to the Land-Based Source, South China Sea. J. Mar. Sci. Eng. 2020, 8, 666.
55. Wu, P.; Huang, J.; Zheng, Y.; Yang, Y.; Zhang, Y.; He, F.; Chen, H.; Quan, G.; Yan, J.; Li, T. Environmental occurrences, fate, and impacts of microplastics. Ecotoxicol. Environ. Saf. 2019, 184, 109612.
56. Wagner, M.; Lambert, S. Freshwater Microplastics: Emerging Environmental Contaminants? Springer Nature: Heidelberg, Germany, 2018.
57. Strungaru, S.-A.; Jijie, R.; Nicoara, M.; Plavan, G.; Faggio, C. Micro-(nano) plastics in freshwater ecosystems: Abundance, toxicological impact and quantification methodology. TrAC Trends Anal. Chem. 2019, 110, 116–128.
58. Prokić, M.D.; Radovanović, T.B.; Gavrić, J.P.; Faggio, C. Ecotoxicological effects of microplastics: Examination of biomarkers, current state and future perspectives. TrAC Trends Anal. Chem. 2019, 111, 37–46.
59. Guerranti, C.; Perra, G.; Martellini, T.; Giari, L.; Cincinelli, A. Knowledge about microplastic in Mediterranean tributary river ecosystems: Lack of data and research needs on such a crucial marine pollution source. J. Mar. Sci. Eng. 2020, 8, 216.
60. Zbyszewski, M.; Corcoran, P.L. Distribution and degradation of fresh water plastic particles along the beaches of Lake Huron, Canada. Water Air Soil Pollut. 2011, 220, 365–372.
61. Li, Z.; Yi, X.; Zhou, H.; Chi, T.; Li, W.; Yang, K. Combined effect of polystyrene microplastics and dibutyl phthalate on the microalgae Chlorella pyrenoidosa. Environ. Pollut. 2020, 257, 113604.
62. De Leo, A.; Cutroneo, L.; Sous, D.; Stocchino, A. Settling Velocity of Microplastics Exposed to Wave Action. J. Mar. Sci. Eng. 2021, 9, 142.
63. Stocchino, A.; De Leo, F.; Besio, G. Sea Waves Transport of Inertial Micro-Plastics: Mathematical Model and Applications. J. Mar. Sci. Eng. 2019, 7, 467.

64. Bianco, A.; Passananti, M. Atmospheric micro and nanoplastics: An enormous microscopic problem. Sustainability 2020, 12, 7327.
65. Bianco, A.; Sordello, F.; Ehn, M.; Vione, D.; Passananti, M. Degradation of nanoplastics in the environment: Reactivity and impact on atmospheric and surface waters. Sci. Total Environ. 2020, 742, 140413.
66. Willis, K.; Hardesty, B.D.; Vince, J.; Wilcox, C. The success of water refill stations reducing single-use plastic bottle litter. Sustainability 2019, 11, 5232.
67. Scarr, S.; Hernandez, M. Drowning in Plastic. Available online: (accessed on 7 April 2021).
68. Ocean Conservancy International Coastal Cleanup. Available online: (accessed on 6 April 2021).
69. Gjyli, L.; Vlachogianni, T.; Kolitari, J.; Matta, G.; Metalla, O.; Gjyli, S. Marine litter on the Albanian coastline: Baseline information for improved management. Ocean Coast. Manag. 2020, 187, 105108.
70. Vlachogianni, T.; Skocir, M.; Constantin, P.; Labbe, C.; Orthodoxou, D.; Pesmatzoglou, I.; Scannella, D.; Spika, M.; Zissimopoulos, V.; Scoullos, M. Plastic pollution on the Mediterranean coastline: Generating fit-for-purpose data to support decision-making via a participatory-science initiative. Sci. Total Environ. 2020, 711, 135058.
71. Simeonova, A.; Chuturkova, R. Marine litter accumulation along the Bulgarian Black Sea coast: Categories and predominance. Waste Manag. 2019, 84, 182–193.
72. Brouwer, R.; Hadzhiyska, D.; Ioakeimidis, C.; Ouderdorp, H. The social costs of marine litter along European coasts. Ocean Coast. Manag. 2017, 138, 38–49.
73. Botero, C.M.; Zielinski, S.; Pereira, C.I.; León, J.A.; Dueñas, L.F.; Puentes, V. The first report of deep-sea litter in the South-Western Caribbean Sea. Mar. Pollut. Bull. 2020, 157, 111327.
74. Scotti, G.; Esposito, V.; D'Alessandro, M.; Panti, C.; Vivona, P.; Consoli, P.; Figurella, F.; Romeo, T. Seafloor litter along the Italian coastal zone: An integrated approach to identify sources of marine litter. Waste Manag. 2021, 124, 203–212.
75. Gerigny, O.; Brun, M.; Fabri, M.-C.; Tomasino, C.; Le Moigne, M.; Jadaud, A.; Galgani, F. Seafloor litter from the continental shelf and canyons in French Mediterranean water: Distribution, typologies and trends. Mar. Pollut. Bull. 2019, 146, 653–666.
76. Zhang, F.; Yao, C.; Xu, J.; Zhu, L.; Peng, G.; Li, D. Composition, spatial distribution and sources of plastic litter on the East China Sea floor. Sci. Total Environ. 2020, 742, 140525.
77. Duncan, E.M.; Davies, A.; Brooks, A.; Chowdhury, G.W.; Godley, B.J.; Jambeck, J.; Maddalene, T.; Napper, I.; Nelms, S.E.; Rackstraw, C. Message in a bottle: Open source technology to track the movement of plastic pollution. PLoS ONE 2020, 15, e0242459.

78. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made—Supplementary Information. Sci. Adv. 2017, 3, 19–24.
79. Castelvetro, V.; Corti, A.; Bianchi, S.; Ceccarini, A.; Manariti, A.; Vinciguerra, V. Quantification of Poly(Ethylene terephthalate) micro-and nanoparticle contaminants in marine sediments and other environmental matrices. J. Hazard. Mater. 2020, 385, 121517.
80. Zhang, F.; Wang, X.; Xu, J.; Zhu, L.; Peng, G.; Xu, P.; Li, D. Food-web transfer of microplastics between wild caught fish and crustaceans in East China Sea. Mar. Pollut. Bull. 2019, 146, 173–182.
81. Gavigan, J.; Kefela, T.; Macadam-Somer, I.; Suh, S.; Geyer, R. Synthetic microfiber emissions to land rival those to waterbodies and are growing. PLoS ONE 2020, 15, e0237839.
82. Rodríguez-Hernández, A.G.; Muñoz-Tabares, J.A.; Aguilar-Guzmán, J.C.; Vazquez-Duhalt, R. A novel and simple method for polyethylene terephthalate (PET) nanoparticle production. Environ. Sci. Nano 2019, 6, 2031–2036.