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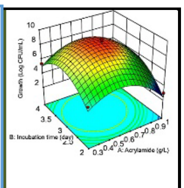

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RSM-Growth on acrylamide

The Microplastics Occurrence and Toxic Effects in Marine Environment

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ABSTRACT

The ubiquitous plastic contaminant is impossible to avoid in today's world and occurs in the marine environment as microplastic particles, which are particles larger than 5 millimeters. It has been discovered that there is pollution in the ocean caused by plastics in areas that were previously thought to be pristine. These areas include the oceans of the Arctic and Antarctic. Many marine ecosystems are negatively impacted by plastic pollution caused by a variety of human activities, which can occur via a variety of pathways. In light of this, the purpose of this review is to talk about marine microplastics while putting an emphasis on the possible occurrence routes taken into marine ecosystems with subsequent sedimentation events. Recent research has pointed to the possibility of using plastic bioremediation as a method for its removal; consequently, this mini review covers the potential exploitation of marine microorganisms and animals has been analyzed in light of the problem of marine plastic pollution.

INTRODUCTION

Microplastics are particles less than 5 mm in size and are widely used worldwide, leading to an exponential increase in their abundance and severe environmental degradation. The world produced about 360 million tonnes of plastic in 2018, an increase of around 12 million tonnes from 2017 [1]. The robustness of plastics, makes them extremely resistant to degradation, which contributes to global plastic pollution in the environment with persistent harmful effects [2–5]. As a result, plastic pollution caused by human activity frequently harms coastal and marine ecosystems [6,7].

A study from [8] suggests that the major contribution in marine plastic pollution is from land–based sources which travel and contaminate the marine environments. In addition, [9] estimated that approximately 9 million tons of land-based sources pollute environment every year. These plastics were accumulated on the sea floor (94%), and near the shorelines (5%), while little of them will stay on the ocean surface (1%) [10]. Several pathways for land–based plastics entering ocean were proposed by [11], including wind transportation, storm water runoff, marine littering and by natural water movements from rivers connecting to their neighbor ocean. Distribution of these plastic pollutants by ocean currents was observed even in some pristine environments such as Antarctic and Arctic Ocean [12–14]. These events imply bad practice of waste management and inadequate developed infrastructure within the affected sites, leading to a worldwide environmental issue later [15] .

Thus, microplastics pollutions in marine water have been acknowledged as a worldwide environmental threats as it poses ecotoxicological and ecological risk to marine organisms and human [16]. Thus, the aim of this review is to discuss microplastics, highlighting the potential routes of them entering the marine environment and their toxic effects in marine water. The challenges and future perspectives in marine microplastic waste management is also discussed.

Marine Microplastics: Transportations & Sedimentations

In recent years, the presence of microplastics in oceanic waters have been reported globally, including few largest oceans in Antarctica, Arctic, Atlantic, Pacific, and Mediterranean regions [12,17–21]. [22] estimated that roughly 7,000 - 35,000 tons of plastics were floated and persisted within the open oceans. Microplastics can enter aquatic environment through different

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pathways contributed by either terrestrial–based or marine–based activities [23]. The indiscriminate and random disposal of plastic waste products contributes to marine litter activity, leading to the direct or unintended transfer of these wastes into the marine waters [24]. [25] highlighted that the terrestrial-based plastic litter was accounted to about 80% of the plastic wastes contributed by the marine litter activity. The accumulation of these microplastics was observed as the marine sediments at the bottom level of the affected marine site.

Microplastics Transportation In Marine Environments

Microplastics from terrestrial regions can be admitted into aquatic environments by the action of the strong wind movements and rapid stream flows [26]. For instance, the natural weathering of macroplastics debris collected within the waste collection ports and landfill treatment sites near the seashore generates microplastics and thus, allowing them to be carried into marine ecosystems via runoff [27]. Besides that, marine–based activities were recognized as the direct transfer of microplastics into the marine environments, including marine tourism events, recreational beaches, and fishing activities [24,28]. For instances, a study from [29] reported the significant amount of microplastics (i.e. about 2300 tiny plastics kg^{-1} dry weight) produced during the peak holiday season on sand beaches from Huatulco, Mexico. These plastic fibers eventually were washed off into marine ecosystems by winds and wave abrasions, raising environmental threats to the marine biota. The well-known plastic pollutants originated from marine–based activities was the intended disposal of broken fishing gears and nets from the fishermen [25,30]. These discarded fishing equipment were degraded by natural fragmentation under solar UV into microplastic and distributed across the ocean, allowing ingestion by small plankton and entering the food chain [31]. To sum up, these events were recognized globally under the category of Abandoned, Lost or Otherwise Discarded Fishing Gear [32].

In addition, domestic and industrial drainage systems are one of the possible microplastic sources in marine environments. For example, the daily use personal care and cosmetic products containing microbeads include shower gels, toothpaste, sunscreen, and abrasive blasting media can be admitted into marine environments via drainage systems discharged from both residential area and their respective manufacturer. In addition, the microplastics particles produced by the synthetic fiber found in fabrics were washed down into local wastewater treatment plants as an effluent [33,34].

Another potential contributor of microplastic pollutions in marine ecosystem is the discharge of the sewage sludge. Undoubtedly, higher fraction of microplastic particles was observed in sewage sludges as compared to the usual effluent [35]. The resulted phenomenon was due to the application of micro–sized sieves filtration system in effluent treatment plants with their pore sizes ranges from 1 mm to 500 mm to trap the microplastics [36]. However, this filtration system was not applied in sewage sludge treatments due to the high concentration of beneficial solid and organic materials within them and thus, filtering process was prohibite. A research in China conducted by [37] suggested that the sewage sludges disposal played a crucial role in microplastic pollution. From the study, 79 samples from 28 wastewater treatment sites in China was used to estimate the average microplastic pollutions (i.e. 1.56×10^{14} particle $year^{-1}$) originated from sewage sludges, and those particles mainly are polyolefin, acrylic particles, polyamide (PA) and PE.

Other route for microplastics entering the marine environments is through the exposure of fecal pellets from the aquatic biota. Due to the microscopic size (< 5 mm) and low–density properties, microplastics were easily transported and distributed from the equator to north/south pole of the Earth by water currents, leading to the accumulation of these tiny plastic particles in most marine ecosystems [38]. These events increased the chances of plastic ingestion by marine biota, especially in zooplankton [39–42]. According to a study by [[41], fecal pellets containing microplastic particles were produced after the introduction of PS with a size of 20.6 µM into the marine zooplankton (i.e. *Calanus helgolandicus* and *Calanus typicus*). By comparison, these fecal particles have density greater than the sea water, thus it sinks to the bottom and were subsequently taken up by the larger marine organisms.

Microplastic Sedimentations in Marine Environments

In recent years, the widespread of microplastics in marine sediments were reported by few numbers of studies, raising the ecotoxicological threats to the marine ecosystems and its biota [43–48]. [48] reported on the average amount (i.e. 240 items kg of dry weighted sediment) of microplastics sediments with their size smaller than 1 mm in western regions of Pacific Ocean. These microplastics were identified as 40% of PE, 27.5% of PET and small fraction of polychlorinated biphenyl. This study confirms the widespread of marine microplastic sediments in deep sea environment from one of the largest oceans in the world.

In general, microplastics were persisted on the water surfaces due to its buoyancy properties [49,50]. The higher density microplastics (i.e. PS, PES & PVC) will be settled down and accumulated as in marine sediments while the lower density microplastics (i.e. PE & PP) will float on the sea surfaces [51,52]. However, there were evidences reported by few studies showing the accumulation of low density polyethylene (LDPE) in marine sediments [48,53,54]. For instances, [54] reported a total 18% of LDPE was found in 28 sediment samples retrieved from Pianosa Island within a depth of 199 to 142 m. These resulted events were due to the biofouling process which led to the settlement of these low density microplastics in marine ecosystems [55]. The density of microplastics was increased by the biofouling of organisms, leading to the negatively buoyant and settlement to the sea floor after their density become larger than that of the sea water [56]. The deeper the water depth, the higher the density of the water, thus these particles were likely to be persisted at a depth equivalent to their respective density after fouling [57].

Aside from the water body, coastal environments include mangrove areas and estuaries can be the potential microplastic retainment sites accumulated in their sediments [58]. There are many factors contributing the condensation of microplastic sediments in these regions. Mangroves often were referred as the optimal setup for the sedimentation process as it accumulates various carbon sources, different nutrients, and rock sediments [35]. [58] further supported the previous statement by reviewing the composition of the coastal environments, in which the biofouling process can be enhanced by the significant amount of organic nutrients associated with the rock sediments in the water. In addition, [59] also highlighted the complex vegetation in coastal environments favors the floating of microplastic particles on the surface.

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Two types of coastal sediments were stated by [60], including allochthonous and autochthonous sediments. The allochthonous deposit (i.e. terrigenous deposit from streams and overflow resuspended sludges) was defined as the ex-situ produced sediments away from the coastal environments, while autochthonous deposit was the in situ produced sediments by the indigenous mangrove organism. These deposits led to the ecological threats to the zooplankton, benthic organisms, and other inhabiting animals in coastal environments [61,62]. For instances, an interesting result reported by [63] stating the abundance of microplastic (i.e. 8 to 5738 items per kg of dry weighed sediment) in mangrove environments from coastal China was 8.5× higher than the polluted free mangroves, and these plastic particles were recognized as 75.2% of PS, 11.7% of PP, 4.6% of rayon, 3.4% of PES, 2.8% of PE and 2.4% of acrylic fibers. The plastic pollutants were identified in various forms from different types of mangrove sediments, including the plastic foams in sandy sediments while plastic fibers and fragments in the muddy one[63]. Another study conducted by [64] reported that approximately 418 microplastic polymers (i.e. PS foams, plastic pellets, plastic fragments and plastic films) with their size ranges from 1 to 5 mm were distributed widely in mangroves from Peninsular Malaysia. They further addressed on the urgent needs in practicing the proper site managements to assure the safety in aquatic food chains in Malaysia. As a result, these microplastics in marine ecosystem are ubiquitous in the present era, raising considerable amounts of adverse effects on the marine biota.

Marine Microplastics: Ingestion by Marine Organisms and its Toxic Effects

The accumulation of microplastics in marine organisms is due to the direct or indirect consumption of persisted tiny plastic particles in aquatic environments. Studies related to the marine microplastic ingestion provide researchers the contamination status of the polluted aquatic sites by characterizing plastic pollutants found inside marine biotas and analyzing their toxic effects on biological organisms. Several factors (i.e. color, size, density, feeding behavior & seasonal exposure) influencing the bioavailability of marine microplastics are also highlighted to better comprehend the effects of microplastics in marine ecosystems.

The uptake and bioavailability of microplastics to the marine organisms

In recent years, the widespread of microplastics has led to the global prevalence of microplastic ingestion by marine organisms in aquatic ecosystems (**Table 1**). Marine plastic pollution can be observed in different types of marine organisms inhabited in various water depths of the aquatic ecosystem, including sea turtles, mussels, fishes, mollusks, crustaceans and other benthic species [65–79]. Several plastic characteristics (i.e. plastic sizes, shapes and colors) were highlighted in **Table 1**, overviewing the differences of microplastic pollution between studies.

In general, most of the study focused on the occurrence of microplastics in the digestive tracts from marine organisms. To date, few potential reasons of microplastic uptakes by these marine organisms were suggested, including the falsely assume microplastics as their prey foods with similar sizes and colors (i.e. visual predators) or accidentally consume foods which has been polluted with microplastics [80–82]. On the other hand, [83] contradicted on the sole concept of microplastic ingestion by marine organisms, in which they highlighted the occurrence of microplastics in non-digestive organs by presenting a theory of microplastics adherence as a novel major uptake by these organisms. In some circumstances, a considerable translocation event of these microplastics was observed in circulatory systems (i.e. hemocytes) and other specific organs (i.e. muscles & liver) of marine organisms [84–86]. Unfortunately, the information on the existence of microplastics in non-digestive organs are underdeveloped, yet more efforts are needed to investigate the potential microplastic adherence in marine organisms for the better understanding on the microplastic accumulation in these organisms. Nevertheless, all uptake methods are equally important as these microplastics eventually accumulated in their digestive tract and raised health concerns to the respective species.

The global prevalence of marine microplastics increases its bioavailability to a broad range of marine biotas [87]. Meanwhile, the almost same characteristics (i.e. color and size) between marine microplastics and marine planktons suppress the bioavailability of prey foods and nutrients to the aquatic organisms [51]. For instances, a considerable amount of microplastics (i.e. 0.33 g/turtle) with a size (i.e. <12.39 mm) was observed in loggerhead sea turtles (*Caretta caretta*), by which these turtles are visual predator that failed to differentiate between their preys and microplastics in the seawater due to the similar color and size. A model study conducted by [88] further supported the previous study by highlighting the preference of sea turtles to consume translucent and flexible plastic particles in their diet as they simply assumed these are jellyfish. The microplastic density is also one of the factors influencing its bioavailability to the organisms by persisting in different water depths made available to the organism stayed within that particular zones [89]. A study conducted by [90] demonstrated a significant amount of microplastics (i.e. 5g in their gut) found in all olive riley sea turtles (*Lepidochelys olivacea*), juvenile green sea turtles (*Chelonia mydas*) and loggerhead sea turtles (*Caretta caretta*) were belong to low density particles, mainly were 51 % of LDPE and 26% of PP due to the high bioavailability of these microplastics which persisted at shallow & intermediate depth of sea waters. Furthermore, high susceptibility of low density PP particles were observed in pelagic fishes by a study from [91], in which 10.7 % of pelagic fishes and 3.4% of demersal fish were recovered from PP microplastic ingestion.

These studies explaining the possible factor on the microplastic bioavailability in marine environments through the density of these tiny particles. Besides that, microplastics bioavailability can be influenced by different feeding behaviors (i.e. types of diet) adopted in respective marine organisms. As an example, a carnivorous gastropod species (*Bolinus brandaris*) was reported with a high amount of microplastic fibers (i.e. 1031.10 ± 355.69 items/kg wet weight) due to the ingestion of contaminated prey clams (*Ruditapes decussatus*) that stayed within the bottom marine sediments which has been exposed to the high level of plastic particles [68]. Another study by [73], on the contrary, reported a significant amount of microplastics was observed in omnivorous fishes (i.e. 61–238 microfiber & microparticle units, MPUs) as compared to the herbivorous (i.e. 14–36 MPUs) and carnivorous (i.e. 10–24 MPUs) fishes. Although there are few studies focused on the effect of feeding behavior within the same marine organism, yet there was no actual comparison made on the influence of feeding behavior adopted by different marine organisms (i.e. between marine fishes and planktons), hence further investigations are greatly needed to elucidate the relationship of feeding behavior in different organisms toward the marine microplastic bioavailability. Another interesting but underdeveloped theory proposed by [92] addressing the possibility on the effect of different seasonal climates to the microplastic bioavailability. In

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the study, they found higher plastic concentration in sea waters during the winter season as compared to the summer season by highlighting the susceptibility of marine seabird, Cassin's Auklet (*Ptychoramphus aleuticus*) to the marine plastic pollution [92]. However, more studies are needed to support this statement by deeper analyzing the relationship of seasonal condition to the marine plastic pollution.

Table 1. Recent reports on the microplastic ingestion by marine organisms in the aquatic ecosystems around the globe. These listed studies were field based assessments, and their several criteria were documented in the table. Notes: A: Plastic size; B: Plastic shape; C: Plastic color; PAN: Polyacrylonitrile.

Location	Organisms	Plastic type	Plastic abundance	Plastic characteristics	Ref
Amazon River estuary	46 fish species	PA & PE	0.7–1.7 particles/fish	A: 0.38–4.16 mm B: Pellets (97.4%), sheets (1.3%), fragments (0.4%) & threads (0.9%) C: Clear, yellow, orange & blue	[65]
Black Sea, Marmara Sea & Aegean Sea, Turkey	Mediterranean mussel (*Mytilus galloprovincialis*)	PET (32.9%), PP (28.4%), PE (19.4%), & etc.	0.69 item/mussel & 0.23 item/g fresh weight of soft tissue	A: <0.5 µm (26.58%); B: Fragments (67.6%), fibers (28.4%), & films (4.05%); C: Blue, black, & white	[66]
Northeast Florida	Sea turtles (*Caretta caretta*)	Not stated	0.33 g/turtle	A: 0.36–12.39 mm B: Hard & sheet plastics are dominant C: White (70%)	[[67]
Adriatic Sea	Benthic flatfish *(Solea solea)*	PVC, PP, PE, PES & PA	1.64-1.73 Items/fish	A; <500 µm B: Fragments (72%) & Fibers (28%) C: Not states	[41]
French Atlantic coasts	Blue mussel & Pacific oyster	PP (47%) PE (38%) PS (4.1%)	0.61-2.1 microplastics/ individual	A: 50-100 µm B: Fragments and filaments	[56]

CONCLUSION

Microplastics are abundant in the marine environment and are generated annually due to the mass consumption of commercial plastic products. Part of the larger plastic debris fragmented into secondary microplastics and were subsequently entered the marine ecosystems by wind motions and ocean currents, while the primary microplastics were transferred through the discharged effluents released from wastewater treatment plant. Microplastic accumulation posed ecotoxicological threats to the marine ecosystems, particularly marine organism on the seawater surfaces or condensed into the marine sediment. PE, PP, PS and PET microplastic have been reported to predominate, causing severe deterioration of physiological conditions and survival rates of marine organisms. After a brief analysis on their origins, transports, and uptakes, undeniably it shows an urgent to investigate and explore the effects of microplastics on a broader range of marine animals, and such information is beneficial in understanding the actual role played by each microplastics in the aquatic organisms.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. PlasticsEurope. Plastics - the Facts 2019: An analysis of European plastics production, demand and waste data. [Internet]. 2019 p. 1–42. Available from: https://www.plasticseurope.org/application/files/1115/7236/4388/FINAL_web_version_Plastics_the_facts2019_14102019.pdf
2. Austin HP, Allen MD, Donohoe BS, Rorrer NA, Kearns FL, Silveira RL, et al. Characterization and engineering of a plastic-degrading aromatic polyesterase. Proc Natl Acad Sci. 2018;115(19):E4350–7.
3. Pruter AT. Sources, quantities and distribution of persistent plastics in the marine environment. Mar Pollut Bull. 1987;18(6):305–10.
4. Van Cauwenberghe L, Claessens M, Vandegehuchte MB, Janssen CR. Microplastics are taken up by mussels (Mytilus edulis) and lugworms (Arenicola marina) living in natural habitats. Environ Pollut. 2015;199:10–7.
5. Yoshida S, Hiraga K, Takehana T, Taniguchi I, Yamaji H, Maeda Y, et al. A bacterium that degrades and assimilates poly (ethylene terephthalate). Science. 2016;351(6278):1196–9.
6. Critchell K, Bauer-Civiello A, Benham C, Berry K, Eagle L, Hamann M, et al. Plastic pollution in the coastal environment: current challenges and future solutions. In: Coasts and Estuaries. Elsevier; 2019. p. 595–609.
7. Vince J, Hardesty BD. Plastic pollution challenges in marine and coastal environments: from local to global governance. Restor Ecol. 2017;25(1):123–8.
8. Haward M. Plastic pollution of the world's seas and oceans as a contemporary challenge in ocean governance. Nat Commun. 2018 Feb 14;9(1):667.
9. Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, et al. Plastic waste inputs from land into the ocean. Science. 2015;347(6223):768–71.
10. Carney Almroth B, Eggert H. Marine plastic pollution: sources, impacts, and policy issues. Rev Environ Econ Policy. 2019;13(2):317–26.
11. Schmidt C, Krauth T, Wagner S. Export of plastic debris by rivers into the sea. Environ Sci Technol. 2017;51(21):12246–53.
12. Isobe A, Uchiyama-Matsumoto K, Uchida K, Tokai T. Microplastics in the southern ocean. Mar Pollut Bull. 2017;114(1):623–6.
13. Lusher AL, Tirelli V, O'Connor I, Officer R. Microplastics in Arctic polar waters: the first reported values of particles in surface and sub-surface samples. Sci Rep. 2015;5:14947.
14. Waller CL, Griffiths HJ, Waluda CM, Thorpe SE, Loaiza I, Moreno B, et al. Microplastics in the Antarctic marine system: an emerging area of research. Sci Total Environ. 2017;598:220–7.
15. Arthur C, Bamford H, Bake J. The occurrence, effect and fate of small plastic debris in the ocean. White Pap Natl Ocean Atmospheric Adm Mar Debris Program Silver Spring Md USA. 2008;1–16.
16. Mrowiec B. Plastic pollutants in water environment. Environ Prot Nat Resour J Inst Environ Prot-Natl Res Inst. 2017;28(4):51–5.
17. Peeken I, Primpke S, Beyer B, Gütermann J, Katlein C, Krumpen T, et al. Arctic sea ice is an important temporal sink and means of transport for microplastic. Nat Commun. 2018;9(1):1–12.
18. Cincinelli A, Scopetani C, Chelazzi D, Lombardini E, Martellini T, Katsoyiannis A, et al. Microplastic in the surface waters of the Ross Sea (Antarctica): occurrence, distribution and characterization by FTIR. Chemosphere. 2017;175:391–400.
19. Pan Z, Sun X, Guo H, Cai S, Chen H, Wang S, et al. Prevalence of microplastic pollution in the Northwestern Pacific Ocean. Chemosphere. 2019;225:735–44.
20. La Daana KK, Officer R, Lyashevska O, Thompson RC, O'Connor I. Microplastic abundance, distribution and composition along a latitudinal gradient in the Atlantic Ocean. Mar Pollut Bull. 2017;115(1–2):307–14.
21. Romeo T, Pietro B, Pedà C, Consoli P, Andaloro F, Fossi MC. First evidence of presence of plastic debris in stomach of large pelagic fish in the Mediterranean Sea. Mar Pollut Bull. 2015;95(1):358–61.
22. Cózar A, Echevarría F, González-Gordillo JI, Irigoien X, Úbeda B, Hernández-León S, et al. Plastic debris in the open ocean. Proc Natl Acad Sci. 2014;111(28):10239–44.
23. Alomar C, Estarellas F, Deudero S. Microplastics in the Mediterranean Sea: deposition in coastal shallow sediments, spatial

variation and preferential grain size. Mar Environ Res. 2016;115:1–10.
24. Cole M, Lindeque P, Halsband C, Galloway TS. Microplastics as contaminants in the marine environment: a review. Mar Pollut Bull. 2011;62(12):2588–97.
25. Andrady AL. Microplastics in the marine environment. Mar Pollut Bull. 2011;62(8):1596–605.
26. Zalasiewicz J, Waters CN, do Sul JAI, Corcoran PL, Barnosky AD, Cearreta A, et al. The geological cycle of plastics and their use as a stratigraphic indicator of the Anthropocene. Anthropocene. 2016;13:4–17.
27. Peng G, Xu P, Zhu B, Bai M, Li D. Microplastics in freshwater river sediments in Shanghai, China: a case study of risk assessment in mega-cities. Environ Pollut. 2018;234:448–56.
28. Alpizar F, Carlsson F, Lanza G, Carney B, Daniels RC, Jaime M, et al. A framework for selecting and designing policies to reduce marine plastic pollution in developing countries. Environ Sci Policy. 2020;109:25–35.
29. Retama I, Jonathan MP, Shruti VC, Velumani S, Sarkar SK, Roy PD, et al. Microplastics in tourist beaches of Huatulco Bay, Pacific coast of southern Mexico. Mar Pollut Bull. 2016;113(1–2):530–5.
30. Napper IE, Thompson RC. Marine plastic pollution: Other than microplastic. In: Waste. Elsevier; 2019. p. 425–42.
31. Montarsolo A, Mossotti R, Patrucco A, Caringella R, Zoccola M, Pozzo PD, et al. Study on the microplastics release from fishing nets. Eur Phys J Plus. 2018;133(11):494.
32. Macfadyen G, Huntington T, Cappell R. Abandoned, lost or otherwise discarded fishing gear. 2009.
33. Murphy F, Ewins C, Carbonnier F, Quinn B. Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. Environ Sci Technol. 2016;50(11):5800–8.
34. Napper IE, Thompson RC. Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. Mar Pollut Bull. 2016;112(1–2):39–45.
35. Auta HS, Emenike CU, Fauziah SH. Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. Environ Int. 2017;102:165–76.
36. Sun J, Dai X, Wang Q, van Loosdrecht MC, Ni BJ. Microplastics in wastewater treatment plants: Detection, occurrence and removal. Water Res. 2019;152:21–37.
37. Li X, Chen L, Mei Q, Dong B, Dai X, Ding G, et al. Microplastics in sewage sludge from the wastewater treatment plants in China. Water Res. 2018;142:75–85.
38. Eerkes-Medrano D, Thompson RC, Aldridge DC. Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. Water Res. 2015;75:63–82.
39. Desforges JPW, Galbraith M, Ross PS. Ingestion of microplastics by zooplankton in the Northeast Pacific Ocean. Arch Environ Contam Toxicol. 2015;69(3):320–30.
40. Frias J, Otero V, Sobral P. Evidence of microplastics in samples of zooplankton from Portuguese coastal waters. Mar Environ Res. 2014;95:89–95.
41. Cole M, Lindeque PK, Fileman E, Clark J, Lewis C, Halsband C, et al. Microplastics alter the properties and sinking rates of zooplankton faecal pellets. Environ Sci Technol. 2016;50(6):3239–46.
42. Vroom RJ, Koelmans AA, Besseling E, Halsband C. Aging of microplastics promotes their ingestion by marine zooplankton. Environ Pollut. 2017;231:987–96.
43. Di M, Wang J. Microplastics in surface waters and sediments of the Three Gorges Reservoir, China. Sci Total Environ. 2018;616:1620–7.
44. Bergmann M, Wirzberger V, Krumpen T, Lorenz C, Primpke S, Tekman MB, et al. High quantities of microplastic in Arctic deep-sea sediments from the HAUSGARTEN observatory. Environ Sci Technol. 2017;51(19):11000–10.
45. Van Cauwenberghe L, Vanreusel A, Mees J, Janssen CR. Microplastic pollution in deep-sea sediments. Environ Pollut. 2013;182:495–9.
46. Tsang YY, Mak CW, Liebich C, Lam SW, Sze ET, Chan KM. Microplastic pollution in the marine waters and sediments of Hong Kong. Mar Pollut Bull. 2017;115(1–2):20–8.
47. Martin J, Lusher A, Thompson RC, Morley A. The deposition and accumulation of microplastics in marine sediments and bottom water from the Irish continental shelf. Sci Rep. 2017;7(1):1–9.
48. Zhang D, Liu X, Huang W, Li J, Wang C, Zhang D, et al. Microplastic pollution in deep-sea sediments and organisms of the Western Pacific Ocean. Environ Pollut. 2020;259:113948.
49. Estahbanati S, Fahrenfeld NL. Influence of wastewater treatment plant discharges on microplastic concentrations in surface water. Chemosphere. 2016;162:277–84.
50. Eriksen M, Mason S, Wilson S, Box C, Zellers A, Edwards W, et al. Microplastic pollution in the surface waters of the Laurentian Great Lakes. Mar Pollut Bull. 2013;77(1–2):177–82.
51. Wang W, Ge J, Yu X. Bioavailability and toxicity of microplastics to fish species: A review. Ecotoxicol Environ Saf. 2020;189:109913.
52. Kaiser D, Kowalski N, Waniek JJ. Effects of biofouling on the sinking behavior of microplastics. Environ Res Lett. 2017;12(12):124003.
53. Harrison JP, Schratzberger M, Sapp M, Osborn AM. Rapid bacterial colonization of low-density polyethylene microplastics in coastal sediment microcosms. BMC Microbiol. 2014;14(1):1–15.
54. Mistri M, Infantini V, Scoponi M, Granata T, Moruzzi L, Massara F, et al. Microplastics in marine sediments in the area of Pianosa Island (Central Adriatic Sea). Rendiconti Lincei Sci Fis E Nat. 2018;29(4):805–9.
55. Chubarenko I, Bagaev A, Zobkov M, Esiukova E. On some physical and dynamical properties of microplastic particles in marine environment. Mar Pollut Bull. 2016;108(1–2):105–12.
56. Katija K, Choy CA, Sherlock RE, Sherman AD, Robison BH. From the surface to the seafloor: How giant larvaceans transport microplastics into the deep sea. Sci Adv. 2017;3(8):e1700715.
57. Ye S, Andrady AL. Fouling of floating plastic debris under Biscayne Bay exposure conditions. Mar Pollut Bull. 1991;22(12):608–13.
58. Zhang H. Transport of microplastics in coastal seas. Estuar Coast Shelf Sci. 2017;199:74–86.
59. Sutton R, Mason SA, Stanek SK, Willis-Norton E, Wren IF, Box C. Microplastic contamination in the San Francisco Bay, California, USA. Mar Pollut Bull. 2016;109(1):230–5.
60. Woodroffe CD, Rogers K, McKee KL, Lovelock CE, Mendelssohn IA, Saintilan N. Mangrove sedimentation and response to relative sea-level rise. Annu Rev Mar Sci. 2016;8:243–66.
61. Hoellein TJ, McCormick AR, Hittie J, London MG, Scott JW, Kelly JJ. Longitudinal patterns of microplastic concentration and bacterial assemblages in surface and benthic habitats of an urban river. Freshw Sci. 2017;36(3):491–507.
62. Hoellein TJ, Shogren AJ, Tank JL, Risteca P, Kelly JJ. Microplastic deposition velocity in streams follows patterns for naturally occurring allochthonous particles. Sci Rep. 2019;9(1):1–11.
63. Zhou Q, Tu C, Fu C, Li Y, Zhang H, Xiong K, et al. Characteristics and distribution of microplastics in the coastal mangrove sediments of China. Sci Total Environ. 2020;703:134807.
64. Barasarathi J, Agamuthu P, Emenike CU, Fauziah SH. Microplastic abundance in selected mangrove forest in Malaysia. In: Proceeding of the ASEAN Conference on Science and Technology. 2014. p. 1–5.
65. Schmid K, Winemiller KO, Chelazzi D, Cincinelli A, Dei L, Giarrizzo T. First evidence of microplastic ingestion by fishes from the Amazon River estuary. Mar Pollut Bull. 2018;133:814–21.
66. Gedik K, Eryaşar AR. Microplastic pollution profile of Mediterranean mussels (Mytilus galloprovincialis) collected along the Turkish coasts. Chemosphere. 2020;260:127570.
67. Eastman CB, Farrell JA, Whitmore L, Rollinson Ramia DR, Thomas RS, Prine J, et al. Plastic ingestion in post-hatchling sea turtles: assessing a major threat in Florida near shore waters. Front Mar Sci. 2020;7:693.
68. Abidli S, Lahbib Y, El Menif NT. Microplastics in commercial molluscs from the lagoon of Bizerte (Northern Tunisia). Mar Pollut Bull. 2019;142:243–52.
69. Pellini G, Gomiero A, Fortibuoni T, Ferrà C, Grati F, Tassetti AN, et al. Characterization of microplastic litter in the gastrointestinal tract of Solea solea from the Adriatic Sea. Environ Pollut. 2018;234:943–52.
70. Sui M, Lu Y, Wang Q, Hu L, Huang X, Liu X. Distribution patterns of microplastics in various tissues of the Zhikong scallop (Chlamys

https://doi.org/10.54987/jemat.v10i2.733

farreri) and in the surrounding culture seawater. Mar Pollut Bull. 2020;160:111595.
71. Sathish MN, Jeyasanta KI, Patterson J. Monitoring of microplastics in the clam Donax cuneatus and its habitat in Tuticorin coast of Gulf of Mannar (GoM), India. Environ Pollut. 2020;266:115219.
72. Collard F, Gilbert B, Eppe G, Roos L, Compère P, Das K, et al. Morphology of the filtration apparatus of three planktivorous fishes and relation with ingested anthropogenic particles. Mar Pollut Bull. 2017;116(1–2):182–91.
73. Mizraji R, Ahrendt C, Perez-Venegas D, Vargas J, Pulgar J, Aldana M, et al. Is the feeding type related with the content of microplastics in intertidal fish gut? Mar Pollut Bull. 2017;116(1–2):498–500.
74. Klangnurak W, Chunniyom S. Screening for microplastics in marine fish of Thailand: the accumulation of microplastics in the gastrointestinal tract of different foraging preferences. Environ Sci Pollut Res Int. 2020;
75. Phuong NN, Poirier L, Pham QT, Lagarde F, Zalouk-Vergnoux A. Factors influencing the microplastic contamination of bivalves from the French Atlantic coast: location, season and/or mode of life? Mar Pollut Bull. 2018;129(2):664–74.
76. Herrera A, Ŝtindlová A, Martínez I, Rapp J, Romero-Kutzner V, Samper MD, et al. Microplastic ingestion by Atlantic chub mackerel (Scomber colias) in the Canary Islands coast. Mar Pollut Bull. 2019;139:127–35.
77. Güven O, Gökdağ K, Jovanović B, Kıdeyş AE. Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. Environ Pollut. 2017;223:286–94.
78. Carreras-Colom E, Constenla M, Soler-Membrives A, Cartes JE, Baeza M, Padrós F, et al. Spatial occurrence and effects of microplastic ingestion on the deep-water shrimp Aristeus antennatus. Mar Pollut Bull. 2018;133:44–52.
79. Waddell EN, Lascelles N, Conkle JL. Microplastic contamination in Corpus Christi Bay blue crabs, Callinectes sapidus. Limnol Oceanogr Lett. 2020;5(1):92–102.
80. Nelms SE, Galloway TS, Godley BJ, Jarvis DS, Lindeque PK. Investigating microplastic trophic transfer in marine top predators. Environ Pollut. 2018;238:999–1007.
81. Ory NC, Sobral P, Ferreira JL, Thiel M. Amberstripe scad Decapterus muroadsi (Carangidae) fish ingest blue microplastics resembling their copepod prey along the coast of Rapa Nui (Easter Island) in the South Pacific subtropical gyre. Sci Total Environ. 2017;586:430–7.
82. Ory N, Chagnon C, Felix F, Fernández C, Ferreira JL, Gallardo C, et al. Low prevalence of microplastic contamination in planktivorous fish species from the southeast Pacific Ocean. Mar Pollut Bull. 2018;127:211–6.
83. Kolandhasamy P, Su L, Li J, Qu X, Jabeen K, Shi H. Adherence of microplastics to soft tissue of mussels: a novel way to uptake microplastics beyond ingestion. Sci Total Environ. 2018;610:635–40.
84. Su L, Deng H, Li B, Chen Q, Pettigrove V, Wu C, et al. The occurrence of microplastic in specific organs in commercially caught fishes from coast and estuary area of east China. J Hazard Mater. 2019;365:716–24.
85. Jovanović B, Gökdağ K, Güven O, Emre Y, Whitley EM, Kideys AE. Virgin microplastics are not causing imminent harm to fish after dietary exposure. Mar Pollut Bull. 2018;130:123–31.
86. Browne MA, Dissanayake A, Galloway TS, Lowe DM, Thompson RC. Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L.). Environ Sci Technol. 2008;42(13):5026–31.
87. Botterell ZL, Beaumont N, Dorrington T, Steinke M, Thompson RC, Lindeque PK. Bioavailability and effects of microplastics on marine zooplankton: A review. Environ Pollut. 2019;245:98–110.
88. Schuyler QA, Wilcox C, Townsend K, Hardesty BD, Marshall NJ. Mistaken identity? Visual similarities of marine debris to natural prey items of sea turtles. BMC Ecol. 2014;14(1):1–7.
89. De Sá LC, Oliveira M, Ribeiro F, Rocha TL, Futter MN. Studies of the effects of microplastics on aquatic organisms: what do we know and where should we focus our efforts in the future? Sci Total Environ. 2018;645:1029–39.
90. Jung MR, Balazs GH, Work TM, Jones TT, Orski SV, Rodriguez C V, et al. Polymer identification of plastic debris ingested by pelagic-phase sea turtles in the central Pacific. Environ Sci Technol. 2018;52(20):11535–44.
91. Rummel CD, Löder MG, Fricke NF, Lang T, Griebeler EM, Janke M, et al. Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea. Mar Pollut Bull. 2016;102(1):134–41.
92. O'Hara PD, Avery-Gomm S, Wood J, Bowes V, Wilson L, Morgan KH, et al. Seasonal variability in vulnerability for Cassin's auklets (Ptychoramphus aleuticus) exposed to microplastic pollution in the Canadian Pacific region. Sci Total Environ. 2019;649:50–60.