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Review

Biological Magnification of Microplastics: A Look at the Induced Reproductive Toxicity from Simple Invertebrates to Complex Vertebrates

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Abstract: The issue of microplastic (MP) pollution is one of the most pressing environmental problems faced today and for the future. Plastics are ubiquitous due to their exponential use and mismanagement, resulting in the accumulation of fragments across the world. Hence, the problem of MP pollution is aggravated when these plastic items disintegrate into smaller particles due to different physical, chemical, and environmental factors. The consumption of these MP pollutants by wildlife is a worldwide concern and a potentially crucial risk for all ecosystems. Consequently, MPs have caused a wide variety of problems for both public health and wildlife concerning vital life processes—specifically reproduction, which is critical to species' survival in an ecosystem. Despite MPs' detrimental effects on wildlife reproduction, it remains unclear how MPs can affect the hypothalamic–pituitary–gonadal (HPG) axis. This review highlights the significant reproductive toxicity of MPs in wildlife, with potentially devastating consequences for human health. The findings emphasize the urgency of developing effective solutions for mitigating the adverse effects of MP pollution on the reproductive systems of wildlife and preserving the integrity of aquatic and terrestrial habitats.

Keywords: microplastics; biological magnification; wildlife health issue; reproductive toxicity; human health risks

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1. Introduction

At present, we are living in a plastic age, where almost 370 million tons of plastic is used and produced annually [1]. Plastics contain a variety of polymers, including polyethylene (PE), polyethylene terephthalate (PET or polyester), polystyrene (PS), polyamide (nylon), polyacrylonitrile (PAN or acrylic), polyvinyl chloride (PVC), polypropylene (PP), and styrene butadiene rubber (for example, car tires). All of these plastic polymers come from carbon-based materials, e.g., petroleum, natural gas, etc. [2–5]. Asia is the main producer of synthetic polymers (50%), followed by Europe (19%), North America (18%), the Middle East and Africa (7%), and Latin America (4%) [3,4]. Globally, a large proportion of the plastic produced is used as a disposable material and is discarded shortly after use [6,7]. In today's world, plastic is used for various purposes, including in packaging, agriculture, electrical appliances, automobiles, etc. [8]. The world today is dominated by plastics due to their durability, water resistance, and ease of processing; therefore, this is considered the plastic era [9]. The amount of plastic waste released into the environment has increased due to the ongoing growth of plastic manufacturing and consumption. Continuous distortions of plastic items caused by weathering decay can result in a huge variety of microplastics (MPs). MPs are pervasive in nearly all aquatic environments, making them accessible to aquatic organisms. Water contamination by MPs is an alarming issue due to their widespread dispersal and possible threat to underwater life. MPs have been identified in a wide array of aquatic systems and seem to be common in freshwater environments in Europe [10–12], North America [13,14], and China [15]. Despite having a major fraction removal of more than 98% of microplastics, a wastewater treatment plant (WWTP) on the Clyde River in Glasgow has been regularly demonstrated to discharge 65 million MPs into the water [16].

In the environment, oversized plastic items disintegrate through physical disintegration, photodegradation, chemical breakdown, weathering, or microbial degradation, causing MPs to form [17,18]. The aim of this study is to conduct a comprehensive review of the literature on microplastic-induced reproductive toxicity. The focus of the review is on examining and synthesizing the existing research, scientific articles, and available data to gain a deeper understanding of the potential harmful effects of microplastics on reproductive health. By analyzing and organizing the findings from a range of scientific sources, this study also aims to provide an overview of the current knowledge and to identify key knowledge gaps in this field. Ultimately, this review is intended to contribute to the existing scientific knowledge, raise awareness about the potential risks associated with microplastics, and inform future research in this area.

2. Types of MPs (Based on Size, Source, and Shape)

Different studies have suggested various definitions of MPs with varying size ranges; for example, MPs can be particles that are smaller than 10 mm [19], smaller than 5 mm [20], smaller than 26 mm [21], smaller than 2 mm [22], or smaller than 1 mm [23–25]. Such diverse definitions create problems when attempting to relate the data discussing MPs; therefore, it is worth introducing a global scientific standard [25,26]. Andray [27] introduced the term "mesoplastics", which are relatively larger than microplastics and can be seen with the naked eye. Koehler [28] presented an updated definition of MPs with their size limits. It was stated that plastic particles >5 mm in size are macroplastics, while plastic particles in the range of 1 to 5 mm are termed mesoplastics, relatively smaller particles with a size of 0.1 μm to 1 mm are microplastics, and particles in the range of <0.1 μm are known as nanoplastics. The fate of microplastics and their behavior when settling along a river are significantly impacted by the particle size of the microplastics [29]. In the marine environment, a very small proportion of relatively smaller plastic particles (<1 mm) was found compared to larger particles (>1 mm), which was possibly due to the size-selective sinks [30]. According to a study employing a hydrodynamic model [29], retention in inland water systems may be a significant factor, and settlement may be responsible for the loss of nanoplastics and the MP fraction. Additionally, that study exposed that there was no consistent link between the size of microplastics and the rate at which they were retained in the sediment. Hu et al. [30], Li et al. [31], and Eo et al. [32] discovered that the quantity of MPs in the sediments was reduced as the particle size increased above 0.5 or 1 mm. Napper et al. [33] revealed that the quantity of MPs in the sediment increased as the particle size decreased, peaked below a specific size threshold, and then began to decline. Experimental findings and those of numerical simulations may differ because of the complexity of physical environments (MPs, for example, may aggregate). Future research on the rate of the settling of microplastics in aquatic environments will require more realistic simulations, including those that involve homogeneous and heterogeneous aggregation [29,30]. Based on the sources, these MPs may be primary or secondary plastic particles, such as the microbeads and pellets that are used in cosmetics, which are considered primary MPs as they are released into the environment with their micro-size [34,35], while secondary MPs are produced when larger polymers break down due to various environmental factors [36–38]. Based on the particles' shape and geometry, MPs have been classified as fragments, films, pellets/granules, sheets, lines/fibers, microbeads, and foams. Microbeads are used in personal care products, such as exfoliants in face scrubs, as well as to deliver drugs in some medical applications [23]. Fibers include MPs shed from synthetic clothes and ropes [39]. Numerous MPs, microbeads, and fibers can infiltrate a watershed and pass through wastewater treatment facilities [23]. In aquatic environments, MPs have been found in various shapes, including fragment, fiber, spheres, film, and pellet shapes, with the fiber and fragment forms making up the majority of the materials [40]. According to Fischer [40] and Wang [41], fibers are more prevalent than fragments in the majority of water bodies. Hoellein et al. [42] discovered, through a simulated experiment, that the settling rate of fragment MPs in freshwater was higher than that of fiber MPs. On the other hand, the uneven forms of fragments may undergo secondary movements that typically slow down the vertical settling velocities and cause them to settle more slowly than other shapes of MPs with comparable sizes [43,44]. By using spherical, short-cylinder, and long-cylinder MPs to measure the settling velocities in water, Yong [45] concluded that the particle shape can influence the settling velocities of MPs.

3. Fate and Biotoxicity of MPs

MPs come from different environmental sources, such as industrial discharge, municipal solid waste, wastewater treatment plants, household discharge, cosmetics, laundry, etc. Once they enter the ecosystem, MPs bioaccumulate, circulate through the food chain, and cause hazardous effects in organisms [46,47]. Many studies have reported the diverse toxicity of MPs in organisms, resulting in, e.g., intestinal defects, decreased survival and reproduction rates, reduced body size, altered behavior, decreased motility, neurotoxicity, increased inflammation, genotoxicity, altered fat and energy metabolism, oxidative stress, and decreased motility [48–60].

3.1. Reproductive Toxicity of MPs in Invertebrates

Reproductive toxicity is a term used to describe harmful effects on any aspect of an animal's reproductive cycle, including gametogenesis, gamete quality, egg manufacture, fertility, and sperm motility [61]. Many studies have proven that MPs cause reproductive toxicity in invertebrates, from cnidarians to echinoderms [19]. In specialized and complex organisms, these MPs and NPs, with reported size ranges of 70 nm to 45 μm, that were taken from the gut reached different sites in their bodies, such as the gonads [62–64]. Only smaller NPs could achieve this, while more prominent MPs may have been stopped from entering by the blood barrier [62]. For example, NPs (240 nm) can change reproductive organs' structural integrity and lead to malfunction. Eom [65] reported reproductive toxicity in cnidarians, in which *Sanderia malayensis* polyps and ephyrae were used as test subjects for the harmful effects of MPs. Non-functionalized polystyrene microbeads with diameters ranging between 1 and 6 μm at a concentration of 10,000 particles mL^{-1} were presented to jellyfish. The MPs haphazardly adhered to the jellyfish's internal and exterior components, with the lengthiest MP addition lasting 52 days during depuration following direct exposure (for 24 h). The asexual reproduction of the *S. malayensis* polyps was significantly decreased after continuous 17-day exposure to MPs. Similarly, in nematodes, regardless of the type of MP, *Caenorhabditis* worms exposed to MPs (1–100 mg L^{-1}) experienced a drop in progeny. Furthermore, Jin [49] concluded that only PE and PVC MPs significantly affected the brood size, while MPs from various sources, including PVC, PP, and PE, significantly reduced the reproductive success in the nematode *Caenorhabditis elegans*.

In the annelid marine worm *Arenicola marina*, the decreased lipid stocks and existing energy induced by MPs led to reproduction complications [66]. In an additional report, when the worm *Enchytraeus crypticus* was treated with MPs, Kwak [67] observed a concentration-dependent impairment in its reproductive competence. According to Eisenia andrei, NP toxicity caused the same effect on the male reproductive organ of earthworms [68].

Aquatic species at various trophic levels have provided the most data on MP-induced reproductive toxicity, with a primary focus on zooplankton. Smaller eggs with a lower chance of hatching were produced when the pelagic copepod *Calanus helgolandicus*, an arthropod and crustacean, was exposed to PS beads over an extended period. The 8-day treatment of the crab arthropod *Ceriodaphnia dubia* with MP beads of natural PE at a concentration 62.5–2000 µg/L and MP fibers at a concentration of 31.25–1000 µg/L resulted in reproductive damage, with a concentration-dependent reduction in the quantity and size of the newborn young [69]. Additionally, both types of MPs had an adult death rate of 40%. Similar findings were seen for the copepod *Tigriopus japonicus*, which was described to have lower fertility when treated with polystyrene MPs (0.5 and 6 µm, 0.125, 1.25, 12.5, and 25 µg mL^{-1}) [70]. Significantly different development times and longer gaps between egg sacs were seen in similar species that were treated with polyethylene and polyamide (12.5 mg L^{-1}) [71]. Ref. [72] Carried out a study in which testicular development in prawns was impaired by exposure to polystyrene MPs (2 and 20 mg/L) for 4 weeks. Exposure to microplastics reduced the rates of embryo deformity, hatching, and larval offspring survival. Ref. [73] demonstrated that 21 days of exposure of the crustacean *Daphnia magna* to MPs (100 µg L^{-1}) harmed their development and reproduction and increased parental death in transgenerational research. In addition, slower rates of population growth and reproduction were seen. These modifications took several generations to manifest themselves, but the authors revealed a slight recovery thereof. Ref. [74] found that there was a decreased offspring number and body size following the exposure of *Daphnia magna* to nano-polystyrene (0.22–150 mg/L for 21 days), which was the cause of newborn abnormalities. The same small planktonic crustacean showed altered reproduction following the same length of exposure to 1 and 5 m MPs (0.012 and 12 mg/L). This included an extended time of first brood emission (49%) and, typically, fewer clutches being released (71%) with MPs at a concentration of 12 mg/L. Other scientists noted that MPs improved the growth of immobile juveniles while decreasing the overall number of progenies [73]. Sand crabs (*Emerita analoga*) were observed to have affected reproduction when exposed to polypropylene fiber MPs with a size of 1 mm for 10 days [75]. According to the findings reported by Gardon [76], MPs/NPs, which are mainly swallowed, can accumulate in male gonads and affect transgenerational reproduction in aquatic and terrestrial species (such as the arthropod *Daphnia magna*). MPs/NPs primarily negatively affect the gametogenesis, embryos, and offspring. Sussarellu et al. [60] examined the effects of the contact of polystyrene MPs with reproduction in the mollusk oyster *Crassostrea gigas* and its progeny. In the exposed oysters, there was a decrease in the sperm swimming speed, fecundity, and gamete and oocyte quality. Further, their progenies were affected by stunted growth in the larval stage. Histological studies indicated that exposure to 6–10 m PS (0.25, 2.5, and 25 µg L^{-1}) for 60 days caused an energy shortage and reduced male gametogenesis in the mollusk oyster *Pinctada margaritifera* [77].

Murano [78] examined the potential impact of polystyrene MPs on the fertilization of the echinoderm sea urchin *Paracentrotus lividus* and found significant drops in the fertilization success rates after MP exposure. Additionally, one sea urchin per litter was placed in an experimental glass tank, where it was exposed to polystyrene (10 and 45 µm, 10 particles/mL) for 72 h. Following fresh tissue extraction, optical microscopy was used to evaluate the quantity of PS in various organs and the gonads, and was shown to be inversely associated with the MP size [79] (Table 1).

Table 1. MP-induced reproductive toxicity in invertebrates.

Group	Species	Toxicity	Reference
Invertebrates Cnidarian	*Sanderia malayensis* polyp and ephyrae	Affected asexual reproduction	[65]
Nematode	*Caenorhabditis elegans*	Drop in offspring	[49]
Annelid	*Arenicola marina*	Decrease in lipid stocks linked to complications in reproduction	[66]
	Enchytraeus crypticus	Impairment of reproductive efficiency	[67]
	Eisenia andrei	Affected male reproductive organ	[68]
Arthropods and Crustacean	*Calanus helgolandicus*	Smaller eggs with a lower chance of hatching	[69]
	Ceriodaphnia dubia *Tigriopus japonicus*	Reproductive damage Lower fertility	[69] [70]
	Tigriopus japonicus	Greater development times and longer gaps between egg sacs	[71]
	Prawn	Impaired testicular development in prawns	[72]
	Daphnia magna	Negative effect on development and reproduction, increase in parental death	[73]
	Daphnia magna	Decreased progeny number, newborn abnormalities	[74]
	Emerita analoga	Negatively affected reproduction	[75]
	Daphnia magna	Mostly negatively affected gametogenesis, embryos, and offspring	[76]
Mollusks	*Crassostrea gigas*	Decreases in sperm swimming speed, fecundity, and gamete and oocyte quality	[61]
	Pinctada margaritifera	Energy deficit and decreased male gametogenesis	[77]
Echinoderm	*Paracentrotus lividus* *Paracentrotus lividus*	Significant drops in fertilization success rates Evaluated the quantity of PS in various organs and the gonads	[78] [79]

3.2. Reproductive Toxicity of MPs in Vertebrates

Like invertebrates, vertebrates are vulnerable to MP toxicity. Reproductive toxicity has also been shown in vertebrates such as fish, birds, and mammals. A study on zebrafish, a freshwater species, and marine medaka, a marine species, was used to test the toxicity of MPs. Dietary polyvinyl chloride and polyethylene (PVC and PET) exposure was conducted over 4 months while using ecologically relevant MP concentrations. The results showed a considerable decline in reproductive output for both species, with the medaka showing a much more dramatic decline in its population [79]. Qiang [80] also reported the use of zebrafish (*Danio rerio*) to examine the impact of MPs (polystyrene) on reproductive organs. No discernible effects were perceived at the lower dosage of 10 mg/L, even with continuous treatment for 21 days. The gonads and livers of both males and females had considerably higher levels of reactive oxygen species (ROS) at doses over 100 mg/L. At a concentration of 1000 mg/L, the male testes showed significantly higher levels of apoptosis, which increased the expression of p53-mediated apoptotic pathways. Histological changes, including a significant reduction in the thickness of the basement membrane of the testis, were also observed by Ismail [81]. Chae [82] conducted a study to inspect the potential defensive properties of a diatom (*Amphora coffeaeformis*) as a food preservative against the harmful impacts on the gonads produced by MPs in Nile tilapia. Tilapia (male) were distributed into groups and pre-fed diets containing *A. coffeaeformis* at four different supplementation levels (0%, 2.5%, 5%, and 7.5%) for 2 continuous months and 10 days (70 days) after being treated with 10 mg/L of MPs for a half month (15 days). The testosterone (T) levels, follicle-stimulating hormone (FSH), and luteinizing hormone (LH), as well as testicular sections and GSI%, were quantified to evaluate the male reproductive success. The Serum LH and T levels both significantly decreased as a result of the exposure to MPs. The fish exposed to MPs had testicular, histological, and degenerative alterations, as well as testis-ova. In fish yolk sacks, NPs bioaccumulated around lipids and passed through embryonic walls due to their hydrophobicity [83]. Adult female marine medaka were subjected to phenanthrene-adsorbed MPs for 60 days to assess the impact of the MPs on the bioaccumulation and the reproductive and transgenerational toxicity of phenanthrene. As a result, phenanthrene bioaccumulation was found to dramatically increase due to the exposure to MPs. Nevertheless, the bioaccumulation level of phenanthrene was smaller when there was no association with MPs. Notably, co-exposure to MPs and phenanthrene at a concentration of 200 μg/L accelerated follicular atresia, prevented ovarian maturation, and exacerbated the reproductive damage. In particular, the embryonic accumulation increased with the MP concentration, and the maternal uptake of phenanthrene might have been passed on to the progeny. Additionally, MPs increased the bradycardia that phenanthrene induced in the embryos, indicating that MPs increased the transgenerational toxicity of phenanthrene [84]. Commercially significant wild dolphinfish (*Coryphaena hippurus)* in the waters of the Eastern Pacific Ocean were reported to have an altered reproductive toxicity due to polyethylene, polystyrene, polypropylene, and polyether sulfone MPs [85].

Many seabirds depend on aquatic species as their chief source of nutrition, so they are easily exposed to plastics when they eat these aquatic species with bioaccumulated microplastics [86]. Since the 1960s, up to 78% of seabird species have been found to have MPs in their gastrointestinal tracts [87,88], and by 2050, almost 99% of more than 300 aquatic bird species are expected to consume plastic fragments [88]. Terrestrial birds have a variety of ecological roles in the food web, making them a crucial part of terrestrial ecosystems [89]. According to Ballejo et al. [90], MPs were found in the gastrointestinal tracts of 16 out of 17 terrestrial bird species. With the exception of the plastic consumption of a few top bird predators, there is little research on terrestrial birds compared to aquatic ones [89,91]. Research has indicated that consuming MPs harms birds' reproductive systems [92]. For instance, male epididymis intraepithelial cysts were more common in Japanese quail chicks with observed plastic intake than in those without [93]. According to Carey [94], adult short-tailed shearwaters (*Ardenna tenuirostris*) can transfer plastics or microplastics to their young.

MP-induced reproductive toxicity is not confined to fish, amphibians, reptiles, and birds, but has also been reported in mammals. Xie [95] studied the molecular mechanisms underlying how polystyrene microplastics (PS-MPs) affect rat ovaries. They concluded that treating rats with polystyrene microplastics resulted in fibrosis due to the activation of the Wnt/catenin signaling pathway and granulosa cell death due to oxidative stress, which reduced the ovarian reserve capacity. Amereh [96] studied the effects of MPs on the reproductive system of male mice. Healthy Balb/c mice were given 6 weeks' worth of exposure to either saline or various doses of micro-PS. The findings demonstrated a major decline in sperm quantity and motility and a considerable rise in sperm deformities following exposure to micro-PS. Another study examined the potential endocrine disturbances of NPs (polystyrene) in male rats, focusing specifically on reproductive toxicity; doses of 1, 3, 6, and 10 mg/kg-day and an exposure time of 5 weeks resulted in alterations in the semen quality, variations in the hormonal environment, and endocrine disruption [97]. Relatively longer exposure to microplastics (polymer type: polystyrene) caused testicle weight loss and a decrease in sperm quantity in male mice [98]. MP exposure (polystyrene with a particle size of 10 μm) in a murine model of allogeneic mating demonstrated an enhanced embryo resorption rate during the peri-implantation phase. The quantity and diameter of uterine arterioles decreased, which meant that the uterine blood supply was lessened. Additionally, although the number of helper T cells in the placenta grew, the proportion of decidual natural killer cells decreased. Finally, a shift in the release of cytokines toward an immunosuppressive condition occurred [99]. Continuous 35-day exposure to polystyrene MPs caused reproductive toxicity in female mice. According to the findings, the blood, large and small intestines, uterus, ovary, heart, liver, spleen, lung, kidney, brain, and other organs of mice could accumulate PS-MPs. Furthermore, after being exposed to PS-MPs, the mouse ovaries had higher levels of IL-6 and lower levels of malondialdehyde (MDA). Additionally, the MPs condensed the rate of first polar body manufacture and the perseverance of superovulated oocytes. In contrast, polystyrene MPs enhanced reactive oxygen species (ROS) and decreased the levels of calcium in the endoplasmic reticulum ([Ca^{2+}] ER), mitochondrial membrane potential (MMP), and glutathione (GSH) in oocytes [100]. Another study determined that MPs (polystyrene) caused greater buildup and oxidative stress in the female ovaries relative to the male testes. After exposure to PS-MPs, the testes of the male mice produced considerably fewer spermatogenic cells and viable epididymis sperm, and the frequency of sperm defects was amplified. Exposure to polystyrene MPs caused a reduction in the ovarian size and follicle count in the female mice. The levels of testosterone, the luteinizing hormone, and the follicle-stimulating hormone were decreased, and the estradiol levels improved in the serum of the male mice after exposure to PS-MPs. In contrast, the changes in the same hormone levels in the serum of the female mice were the opposite. The microplastic-exposed animals had a lower conception rate, resulting in fewer embryos. These results imply that the exposure to PS-MPs harmed the reproductive systems and caused oxidative stress, testicular and ovarian damage, altered blood hormone levels, and impaired reproduction and fertility. Regarding reproduction and fertility, female mice seem more vulnerable to MPs than male mice [101]. MP exposure in albino mice caused a reduction in the volume, motility, and number of sperm in the epididymis. Additionally, the amount of serum testosterone was also significantly reduced. Histological analysis of the testicular architecture revealed deformed testes, with the largest percentage of vacuolated seminiferous tubules, elevated catalase, and reduced superoxide dismutase activity. This report contributes to our understanding of reproductive toxicity in mammals due to microplastic exposure and oral intake. The potential toxicity of microplastics in terrestrial animals was shown by demonstrating that the oral intake of PS-MPs impaired male rats' reproductive function [102]. Li [102] confirmed that microplastics (polystyrene) caused harm to the seminiferous tubules, caused the death of spermatogenic cells, and decreased their quality and motility, leading to abnormalities. The findings showed that 4- and 10-micrometer PS-MPs accumulated in the mouse testicles after 24 h of exposure. In addition, when the exposure time was increased by up to one month, the levels of testosterone, an important sex hormone, dropped, and the sperm was affected. Spermatogenic cells were disorganized and abscised, and multinucleated gonocytes were seen in the seminiferous tubules, according to H&E staining [63]. The findings revealed that there were considerably fewer viable epididymis sperm following polystyrene MP exposure; using Duff–Quik staining, it was discovered that the MPs amplified the rate of sperm deformity. After exposure to PS-MPs, HE and TUNEL labeling revealed the reduction, shedding, and death of sperm cells at all stages of the testes [103,104]. MPs contaminated with PAE caused increased reproductive toxicities that were seen as more significant changes in the physiology and spermatogenesis of the sperm. The changes in the testicular transcriptome and exacerbation of oxidative stress caused by PAE-contaminated MPs further supported the increased toxicities. [105]. For 180 days straight, mice were given water that contained 100 μg/L and 1000 μg/L of polystyrene MPs with particle sizes of 0.5 μm, 4 μm, and 10 μm, which resulted in testicular damage, an altered shape, and lower serum levels of testosterone, LH, and FSH. Additionally, it caused sperm damage [106] (Table 2).

Table 2. MP-induced reproductive toxicity in vertebrates, including human beings.

Group	Species	Toxicity	Reference
Fishes	*Oryzias latipes*	Considerable decline in reproductive output	[80]
	Danio rerio	Male testes showed significantly higher levels of apoptosis, and gonads and livers had considerably higher levels of reactive oxygen species (ROS)	[81]
	Oreochromes niloticus	Mostly affected gonads	[82]
	Oreochromes niloticus	MP had testicular, histological, and degenerative, testis-ova alterations	[83]
	Coryphaena hippurus	Affected reproductive function	[84]
Birds		Hazardous to birds' reproductive systems	[92]
	Coturnix japonica	Intraepithelial cysts in the male epididymis	[93]
	Ardenna tenuirostris	Transferred microplastics to young	[94]
Mammals	Rats	Fibrosis, granulosa cell death due to oxidative stress, reduced ovarian reserve capacity, affected rat ovaries	[95]
	Mouse	Significant decrease in sperm quantity and motility	[96]
		Semen quality, changes in the hormonal environment	[97]
		Decreased sperm number and changed sperm phenotype	[98]
		Reduced the rate of first polar body extrusion and the survival of super-ovulated oocytes	[99]
		Fewer spermatogenic cells and viable epididymis sperm, and the frequency of sperm deformity was increased	[100]
		Increased reduction in ovarian size and follicle count in female mice, levels of testosterone, and luteinizing hormone	[101]
		Volume, motility, the number of sperm in the epididymis, and the amount of serum testosterone were all significantly reduced	[102]
		Damage to seminiferous tubules caused the death of spermatogenic cells and lowered sperm motility and concentration while increasing sperm abnormalities	[103]
		The sperm quality and testosterone levels of mice decreased	[106]
		Increased the rate of malformation, shedding, and death of sperm cells at all levels of the testes	[104]
		Significant changes in the physiology and spermatogenesis of sperm, changes in the testicular transcriptome, and exacerbation of oxidative stress	[105]
Humans		MPs less than 700 nm were quantified in human blood	[107]
		Evidence of MPs in six human placentas that were taken from consenting women	[108]
		Human placenta and meconium samples were found to contain MPs	[109]
		Microplastics in 17 placentas	[110]
		Presence of MPs in human placentas	[111]
		MPs were quantified in women's breastmilk	[112]

4. Evidence of MPs in Human Tissues

Human beings are also exposed to MPs and NPs through contaminated food and the inhalation of contaminated air. Recently, many studies have detected MPs in human blood. Many reports that quantified MPs in human materials, including blood, have been published in this regard, such as that of Leslie [108], who quantified NPs with a size of 700 nm from human blood samples. In their study, the most abundant polymers that they identified in human blood were polyethylene, styrene, and polyethylene terephthalate. Ragusa [109] found clear evidence of MPs in six human placentas taken from consenting women with healthy pregnancies and examined them using Raman microspectroscopy to determine whether microplastics were present. A study was designed to check for MPs larger than 50 µm in placental tissue and meconium samples taken during two breech births via cesarean section. The presence of 10 prevalent forms of microplastics was examined using Fourier-transform infrared (FTIR) microspectroscopy in placenta and stool samples following the chemical digestion of non-plastic material. This study found polyurethane, polyethylene, polypropylene, and polystyrene [109]. Using direct laser–infrared (LD-IR) spectroscopy, Ref. [110] examined the existence and features of microplastics in 17 placentas. All of the placenta samples contained microplastics, with an abundance ranging between 0.28 and 9.55 particles/g and an average of 2.70 to 2.65 particles/g. There were 11 different types of polymers found in these microplastics, including polyvinyl chloride (PVC, 43.27%), polypropylene (PP, 14.55%), and polybutylene succinate (PBS, 10.90%). These microplastics had diameters ranging between 20.34 and 307.29 µm, and the majority (80.29%) were under 100 µm. While fibers predominated among the larger microplastics (200–307.29 µm), fragments made up most of the smaller microplastics. A TEM (transmission electron microscopy) study of ultrathin slices of 10 placenta samples revealed MP particles in the villi compartment of the human placenta [111]. Recently, MPs were quantified in human breast milk and other aquatic organisms. In that study, the researchers extracted MPs from 26 out of the 34 samples. The most significant polymers that were extracted were PVC, PET, and PP, with a size range of 2–12 µm [112–116] (Table 2).

5. Conclusions and Recommendations for Future Directions

This study presents a comprehensive review of the adverse impacts of MPs on the reproductive systems of animals, from simple invertebrates to complex vertebrates. Many studies have shown reproductive toxicity in animals. However, research in this direction is still limited. The research gaps must be filled and studied to understand the alarming vulnerabilities to and behavior of MPs.

The following measures are recommended for the control of MP pollution:

- MP pollution is an ecological problem that crosses borders and affects the entire world. The damage caused by MP pollution has an impact everywhere and is not limited to a specific location. As a result, international aid and a coordinated reaction from all governments are required for the management and mitigation of MP pollution.
- On one hand, active participation in international conferences is advised to enhance global communication, coordination, and policy suggestions for the prevention of MP pollution.
- A critical step in lowering MP contamination is source minimization. Strong regulations should be used to regulate the manufacturing and trading of products that could harm the environment with MPs at the source. Due to their detrimental effects, microplastics such as microbeads have been outlawed for industrial use in several nations. For instance, the Microbead-Free Water Act, which was adopted in the United States in 2015, made the use of microbeads illegal.
- Many people are interested in the development of a strategy for the biological elimination of MPs, which can be broken down by some environmental microbes. This is currently an effective way to prevent and control microplastic pollution and a great way to deal with non-biodegradable plastics. At the same time, due to processing costs, breakdown efficacy, and other limitations, biodegradable polymers cannot completely replace conventional plastics.
- In Pakistan, there are no precise rules governing MP contamination. However, the nation still has legislation in its capital that governs and bans the usage of plastics,

such as polyethylene bags. These plastic-ban regulations aid in the first phase of the development of additional regulations for combatting plastic contamination.

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