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Some Behavioural and Physiological Effects of Plastics (Polyethylene) on Fish

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ABSTRACT: Waste generation and disposal, particularly of plastics, have grown significantly over time due to the rapid expansion of urban development. Aquatic species are especially threatened by plastic pollution because the aquatic ecosystem serves as a sink for all contaminants. The capacity for regular development and reproduction is crucial for both human and wildlife health. The endocrine system, which comprises numerous glands that emit hormones to control blood sugar, growth, reproduction, metabolism, and the development of the brain, normally controls these functions. The majority of the synthetic organic chemicals used in plastics come from petroleum. It is well known that their effects cause the endocrine system's regular operation to be disrupted. Plastics are produced at a low cost, and their light weight and adaptability make them candidates for a wide range of uses in all facets of daily life. Plastic waste can enter the ecosystem through waste discharges from oil and gas platforms, aquaculture, and landfills, as well as through litter such as bags and plastic bits used as abrasives. Because they include indigestible particles that fill the stomach and lessen appetite, plastics have been implicated in harming the health of a variety of creatures. They were also discovered in the gastrointestinal tract of individual fish after one week, which disrupted the food's flow to the intestinal mucosa and had an impact on the fish's growth and physical condition. Additionally, fish exposed to plastics have been shown to exhibit changed behavior, decreased sperm motility, and increased thyroid hormone production. Therefore, exposure to varied amounts of polyethylene impairs an organism's normal physiological functioning and has the potential to impact negatively on both the health of the organism and its offspring. This review was aimed at highlighting the risks of plastic exposure to fish and people through the food chain.

KEYWORDS: Homeostasis; hormone; malfunction, ocean; sink

1. Introduction

Numerous environmental chemicals have harmed both humans' and other animals' regular physiological processes over time. Concern has recently been expressed about a class of man-made and natural pollutants that act as endocrine disruptors [1]. Endocrine-disrupting chemicals (EDCs) are the collective name for these substances, which include heavy metals, plastics, additives, a wide range of anthropogenic organic compounds, steroids, and steroid-imitating substances [2]. EDCs mimic or oppose the activity of endogenous hormones, interfere with their production, metabolism, transport, and excretion, and affect the levels of hormone receptors, among other physiologically normal processes [3].

Endocrine-disrupting substances are xenobiotics that bind to the body's endocrine receptors and activate, alter, or block the synthesis of natural hormones. They are found in manufactured goods such as plastic bottles, children's toys, toothpaste, polyvinyl chloride pipes, detergents, and cosmetics [4]. Through the study of Colborn in 1991 and later studies by UNEP and WHO, respectively, the term "endocrine-disrupting chemicals" (EDCs) became well known [5]. Aquatic creatures are particularly at risk from EDCs' actions since the aquatic environment serves as a sink for chemical compounds [6, 7]. Research on the consequences of EDC exposure during the previous 20 years has identified a variety of effects on growth, development, and reproduction in both people and wildlife [8]. Endocrine disruption is a problem that may have ecological consequences. These hazardous substances affect or prevent the activity of hormones required for wildlife reproduction. An exogenous substance known as an "endocrine disruptor" interferes with the body's endogenous hormones that are necessary for maintaining a stable equilibrium, development, reproduction, and behavior by blocking their formation, secretion, transfer, binding, function, or removal [9]. EDCs are a widespread and international issue. These compounds are all around us; they can be found in the air, water, and sediment [10]. Several are quite stable and capable of moving up the food chain. The hormones are chemical compounds that are created spontaneously by organisms and are biologically highly active even at low concentrations [3]. Over 85,000 man-made compounds are produced, thousands of which are EDCs [6]. Hormones regulate a wide range of bodily systems in both humans and animals, including metabolism, sexual development, reproduction, immunity, the sleep-wake cycle, growth, mood management, and the stress response [11]. The effects of several of these hormones are gradual but persistent. Also including EDCs are soft plastics (containing tribromophenol, bisphenols, and UV filters), rubber (containing resorcinol and triphenyl phosphate), electronics and textiles (containing PFOS and BFRs), and cosmetics [12]. The majority of the synthetic organic chemicals used in plastics come from petroleum. Plastic polymers are rarely used alone; instead, they often combine with different additives to enhance performance. Among the additives used are inorganic fillers such as silica and carbon that reinforce the materials, together with plasticizers that make the material flexible, thermal and ultraviolet stabilizers, flame retardants, and coloring agents. Such additives are used widely and in large amounts in a variety of products.

The most prevalent plastic is polyethylene. Polyethylene is polymeric ethylene polymer used to make electrical insulation and packaging. Its main application is in packaging, including plastic bags, kid's toys, geo-membranes, bottles, and some other containers [13]. Because of its versatility as an abrasive ingredient, adhesive, binder, bulking agent, emulsion stabilizer, film former, oral care agent, and viscosity-increasing agent, it is frequently used in formulas for makeup foundations and compressed powder cakes, skincare and beauty products such as eyeliners, mascara, eye shadows, eyebrow pencils, lipstick, and blushers, as well as skin cleansers. While some hazardous substances, such as pesticides and other industrial chemicals, are chemically drawn to plastics due to their hydrophobic nature, they are not introduced to plastics during manufacture [14]. These substances enter the water from various sources, and because they are hydrophobic, they do not linger there. Instead, they adhere to surfaces, such as floating pieces of plastic, and become highly concentrated there, where they can be consumed by fish, sea turtles, and birds. Then, these substances can enter the body and concentrate in fat tissue (lipids). López [15] gave a report on the impact of national bans and levies on plastic bag usage and the increasing figures (Figure 1), while Gutow [16] gave similar increasing values for 2050 projections of global plastic production and future trends (Figure 2).

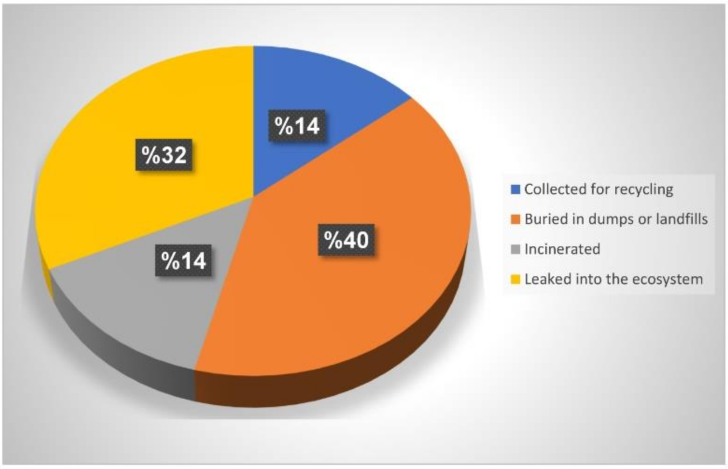

Figure 1. Impact of national bans and levies on plastic bag usage [15].

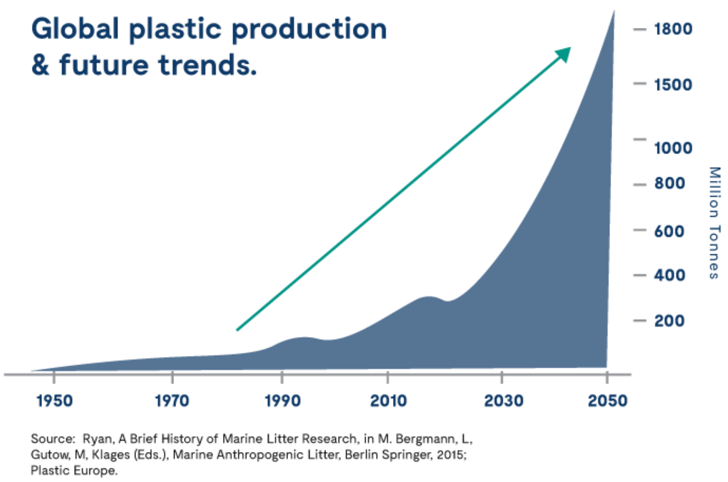

Figure 2. Global plastic production and future trends [16].

1.1. Classification of plastics.

Plastics are fossil fuel products. They are synthesized from fossil fuel (oil and natural gas), a feedstock, and molecules extracted from the oil and gas [17]. Plastics are divided into two general categories: (i) thermoplastics; (ii) thermosetting plastics [18]. Thermoplastics: Thermoplastics have either linear or branched structures and can be amorphous or semi-crystalline materials. Polymeric chains are held together by Vander Waal's weak forces. Thermoplastic softens on heating and hardens on cooling because of weak Vander Waal's forces. These plastics can be remolded, reshaped, and reused. Thermoplastics can be recovered from waste. Examples of thermoplastics are cellulose derivatives, polyamides, polystyrene, polyvinyls, polyethylenes, etc. The polymeric chains in thermosetting polymers are held together by cross-links in three-dimensional, cross-linked network topologies (strong covalent bonds). These plastics are hard, robust, and brittle, and they do not soften when heated. Thermosetting plastics cannot be remoulded and are therefore not recyclable. Phenolic resins (bakelite), polysters (terylene), and other materials are examples of thermosetting plastics.

1.2. Nature and characteristics of polyethylene.

There are four different forms of polyethylene compounds, with high-density polyethylene (HDPE) and low-density polyethylene (LDPE) being the two most popular types [19]. Low-density polyethylene (LDPE) is a material that is very flexible and flows in a unique way. This makes it a great choice for shopping bags and other plastic film applications.With a linear shape and a melting point of 115°C, LDPE has a high degree of ductility but a low degree of tensile strength, which is demonstrated in the real world by its inclination to stretch under stress. The qualities of linear low-density polyethylene (LLDPE), which is very similar to LDPE, can be changed by altering the formula's ingredients, and the production of LLDPE uses typically less energy than that of LDPE. High-density polyethylene (HDPE) is a tough, high-density plastic that melts at 135 °C and has a modest amount of stiffness and a branching, highly crystalline structure. Cutting boards, garbage cans, laundry detergent bottles, and milk cartons are just a few items that are often used as materials.

The highly dense form of polyethylene known as ultra-high molecular weight polyethylene (UHMW) often has molecular weights many orders of magnitude higher than HDPE. It is commonly used in high-performance equipment like bulletproof vests because it can be spun into threads with tensile strengths several times greater than steel. Low in strength, hardness, and rigidity, polyethylene possesses great ductility, impact strength, and low friction. Under constant pressure, it exhibits significant creep, which can be lessened by the insertion of short fibers. The melting point of the polyethylene, which is 80°C, places a limit on its utility. Low-density polyethylene used in commercial applications typically melts at temperatures between 105 and 115°C. The type of polyethylene has a significant impact on these temperatures. Non-polar, saturated, high-molecular-weight hydrocarbons make up polyethylene. Nearly no water is absorbed by polyethylene. Only polar gases have a lower gas and water vapor permeability than most plastics, yet oxygen, carbon dioxide, and flavorings can easily get through. When PE is exposed to sunlight, it can become brittle; typically, carbon black is employed as a UV stabilizer. They provide good tracking resistance and are effective electrical insulators. Ethylene, also known as ethene by the IUPAC, is a gaseous hydrocarbon with the chemical formula C_2H_2, which can be thought of as two methylene groups ($-CH_2-$) joined together. Ethylene needs to be very pure because the chemical is very reactive. Radical polymerization can be used to create polyethylene, although this method has limited application and often requires high-pressure equipment [20].

Like other plastics, polyethylene is made by distilling hydrocarbon fuels (in this case, ethane) into lighter groups called "fractions." Some of these fractions are then mixed with other catalysts to make polymers, usually by polymerization. PE is known as a "thermoplastic" (as opposed to a thermoset). A thermoplastic substance becomes liquid when it reaches its melting point (LDPE and HDPE have melting values of 110 and 130°C, respectively). One of the most useful qualities of thermoplastics is their capacity to be heated to their melting point, chilled, and then warmed repeatedly without severely deteriorating. Thermoplastics, such as polyethylene, liquefy rather than burn, making them easy to recycle. Thermoset plastics, on the other hand, can only be heated once. It is through the process of initial heating that thermoset materials undergo solidification and experience an irreversible chemical change. A second attempt to heat a thermoset material to a high temperature would result in combustion. Due to this characteristic, thermoset materials are deemed unsuitable for recycling purposes.

1.3. Endocrine disrupting components of polyethylene.

Many food-containing goods are made of thermoplastics, which are produced by polymerizing a specific monomer or monomers in the presence of catalysts at high molecular heat utilizing boiling or dishwashing. A plastic object with several parts, such as a baby bottle, may contain up to 1000 chemicals, almost all of which can leach from the product, particularly when stressed. A single component may have 5 to 30 compounds [21]. According to Darbre [22], phthalate ester and bisphenol A, which are employed as plastic additives, have endocrine-disrupting qualities. They interfere with the activities of various hormones in aquatic species and people via the food chain when they leach into the aquatic habitat. Epoxy resins and polycarbonate plastics are derived from phenolic monomers, which are systemic poisons to the reproductive and developmental systems and are classified as EDCs [23].

2. Occurrence of Polyethylene in the Environment

Density and buoyancy of plastic particles, current and water flow, wind and weather conditions, oceanic geographical features, the presence of large rivers, proximity to urban areas, industrial and wastewater treatment discharges, proximity to trade routes and shipping channels, and the number of fishing activities are all things that affect the amount of plastic in the ocean [24]. Plastics break down and release dangerous chemicals when they are used, recycled, thrown away, or left lying around as trash. Most plastic trash is made on land, such as when people throw things away on purpose or by accident [25]. Plastics can get into the environment in a number of ways, such as when bags, bottles, and other plastic items are thrown away [26], when microscrubbers like acrylic and polyester are blasted at boat hulls, engines, and machinery to remove rust or paint, when pieces of low-density polyethylene film from silage bags, bunker silo covers, and silage end up on farmlands, and when wastewater effluent is dumped into the environment [26]. On ship decks, pre-made resin polyethylene and polypropylene pellets have been used to make it easier to move large objects. However, they can wash off the deck by accident or because they were not handled or stored properly [27]. The proximity of the source, particularly in urban areas, is an important factor influencing the amount of plastic in the aquatic environment [24]. Plastic waste is regularly colonized by fouling organisms such as algae, biofilinas, and invertebrates, causing it to sink to the ocean floor and mingle with the silt [28]. Furthermore, because they protect the plastic surface from UV light, organisms that colonize plastic waste may minimize photolysis-induced degradation [29]. Plastics move at different speeds in the environment due to their various sizes, weights, and forms. Lightweight plastic products and particles (such as bags, films, textile fibers, pellets, and plastic bottles) are more easily transported over greater distances by wind, weather events, storm water, effluent discharges, and inputs from freshwater systems than more dense and bigger plastic things.

3. Behavioural and physiological effects of polyethylene

3.1. Behaviouraleffects of polyethylene

A previous study compared school-wide aggregation and rheotactic reactions to food odor presentations in wild-collected schools of northern anchovy (*Engraulis mordax*) to alternative solutions made of plastic debris and clean plastic. They discovered that anchovy schools responded to plastic trash odor with greater aggregation and decreased rheotaxis. They found that the results were similar to the effects of food and food odor presentations on schools and that these behavioral responses were absent in the clean plastic and control treatments. They also discovered that adult anchovies foraged using scents [30]. Other studies discovered that fish exposed to plastic additives changed their behavior. The effects of tiny plastics (20mm) on the ocean and discovered significant changes in fish behavior [31, 32].

3.2. Growth effects of polyethylene.

Microplastic in the digestive system of juvenile planktivorous fish (*Acanthochromis polyacanthus*) was the subject of a one-week study [33]. They were found to impair the health and development of the fish. In a lab experiment, Mbugani et al. [34] exposed European perch larvae to microplastic particles at concentrations seen in oceans, and found that the larvae grew more slowly as a result. Kühn et al. [35] examined the gastrointestinal tracts of 290 northern and Baltic Sea fish species, including demersal (cod, dab, and flounder) and pelagic (herring, mackerel) species, to determine the prevalence of plastic ingestion. Seventy-four percent of all particles were in the microplastic (5mm) size range, and forty percent of the particles were made up of polyethylene (PE). Using a microscope, Batel et al. [36] found tiny pieces of plastic embedded in dried blood samples taken from a blue mussel.

Figure 3. A rainbow runner in the North Pacific Gyre that had ingested 18 pieces of plastic [24].

3.3. Reproductive effects of polyethylene.

In a laboratory experiment with European perch larvae, Mbugani et al. [34] discovered that exposure to microplastic particles at concentrations seen in the ocean prevented fertilized eggs from hatching, restricted larval development, reduced activity levels, and raised death rates. According to Bajt [31], oxidative stress reduces the motility of sperm. Ingestion of polystyrene particles inhibited *C. gigas*' capacity to reproduce [37]. Liu et al. [38] discovered that polybrominated diphenylethers (PBDEs) harmed both the male and female reproductive endocrine systems of zebrafish and altered zebrafish gene expression [39].

Figure 4. Microplastics visible in a pike [40].

Scientists have revealed for the first time that fish exposed to such substances during their development exhibit stunted growth, higher death rates, and altered behavior that might threaten their survival. Perch larvae were seen to not only consume plastics, but also to prefer them over their natural meal. Perch larvae having access to microplastic particles ignored their normal food supply, plankton, and consumed only the plastics (microplastics visible in a pike).

3.4. Effect of polyethylene on endocrine systems

According to Flaws et al. [41], PCBs absorbed via plastic altered the regulation of vital hormones such as thyroxine, oestrogen, and testosterone. It has been demonstrated that deteriorated polymer structures have a greater biological activity [42] due to the increased leaching of endocrine-disrupting chemicals produced from plastic and their capacity to interfere with energy metabolism. According to a field study by Bilal et al. [43], up to thirty percent of persons have plastic in their gastrointestinal systems. Similarly, Prakash et al. [44] found that Japanese medaka exposed to mm-sized polyethylene particles exhibited early indicators of endocrine disruption. According to experimental study examining the effects of compounds associated with plastics on invertebrates and fish, both the chemicals and the plastic itself have negative effects on these organisms [45]. According to a research, the mean concentrations of hydrophobic organic compounds in the body tissues of fish (Japanese medaka, *Oryzias latipes*) fed polyethylene pellets at 10% of their diet were between 1.2 and 2.4 times greater than those of control fish that were not fed pellets [46]. Also, low-density polyethylene pieces were placed in San Diego Bay, California, by [46]. After three months, the levels of total PBDEs, PAHs, and PCBs on the polyethylene were found to be 1,4, and 15 times higher than those found on virgin low-density polyethylene, indicating that these pollutants had attached themselves to the plastics from the seawater. In a long-term field experiment, Cousin et al. [46] discovered that polyethylene absorbs more organic pollutants than other popular polymers. They argued that high and low density polyethylene made it easier for PCBs and PAHs to absorb. Paul et al. [47] treated fish to three treatments: virgin plastic (also referred to as virgin polyethylene pre-production pellets), non-plastic (sometimes referred to as negative control), and marine plastics. Male fish exposed to marine plastic had changed gene expression, but both male and female fish exposed to virgin plastic exhibited altered gene expression. They anticipated that the endocrine systems of adult fish may be influenced by ambient levels of plastic garbage ingestion. According to Aliakbarzadeh et al. [48], the AchE activity of common goby treated with polyethylene with or without pyrene decreased significantly, suggesting the enzyme's vulnerability to disrupt neurotransmission signaling. In addition, they hypothesized that the exposure caused alterations in metabolic profiles. The structural and functional characteristics of the gut of European sea bass are affected by microplastics [49].

4. Conclusions

It has been demonstrated that synthetic chemicals used in the production of plastics seep into the environment and that their effects interfere with normal physiological activities. At now, at least 8 billion kilos of plastic being poured into the seas annually, which is comparable to a garbage truck's worth of plastic being tossed into the ocean every minute. Based on the expected growth rates, by 2050, the oceans will receive the equivalent of one truckload of plastic every 15 seconds, day and night. And by 2050, if we don't substantially limit plastic manufacturing and dumping, the amount of plastic in our seas will exceed the mass of fish. The recycling rate for all plastics, including plastics used in buildings and autos, is 18 percent. The recycling rate for plastic packaging (water bottles, chip bags, supermarket packaging, etc.) is barely 14%; one-third of plastic packaging entirely evades garbage collection systems and is lost to the environment on roadside or in waterways. Plastic persists in the water as ever-smaller particles for generations. This extensive pollution is exacerbated by human activities like as overfishing, ocean acidification, and rising water temperatures. The worldwide production of plastics should be reduced by the execution of measures. The impact of persistent plastics and their chemical additives, hazardous POPs and EDCs on marine biota and their bio-magnification in the food chain, as well as the health and financial repercussions of exposure, should all be investigated scientifically. To successfully reduce the demand for persistent plastics, the government must swiftly enact the necessary steps. These measures might include prohibitions on the use of plastic bags in personal care goods and the imposition of environmental fees on single-use plastic products made from non-biodegradable materials. In addition, it is suggested that efforts be made to promote the replacement of harmful chemicals in the manufacturing of plastics.

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Competing Interest

The authors declared there were no conflicts of interest among them.

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