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Microplastics, The Environment, and Reproductive Health: How is The Accumulation of Microplastics in our Environment and Bodies Impacting Reproductive Health?

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SIT Study Abroad

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Abstract

As global trends in both production and consumption of plastics continue to evolve, the bioaccumulation and biomagnification of microplastic particles in our everyday lives follow suit. This increasingly relevant problem has only recently been explored in the context of global health, and more specifically, reproductive health. Along with this steady increase in plastics and our exposure to them, researchers have separately observed adverse patterns in reproductive health. The chemicals involved throughout the microplastic life cycle may be playing a key role in these simultaneous patterns. With the aid of previous studies and publications on microplastics, exposure pathways, endocrine disruptors, and reproductive health, the goal of this paper is to establish the linkages between these topics and explore the possibility of a causal relationship.

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Ⅰ. Introduction

The purpose of this independent research project is to investigate the relationship between microplastics and reproductive health. The overarching topic of microplastics was chosen because of its interdisciplinary nature and increasing salience in both global and environmental health. In the process of gathering resources and information about how microplastics influence environmental and human health, came the decision to narrow the focus of impacts to reproductive health. This decision to look closely at the relationship between reproductive health and microplastics was made for several reasons. For one, the term "microscopic plastic" is relatively new to the academic world with its first publication in 2004 (Harris, 2022). While there is sufficient evidence and research confirming the prevalence of these microscopic plastics in our environment and bodies, analysis and exploration into their impacts are lacking. Furthermore, the topic's intimidating name and recent debut into public view as a health problem allows for an alarming reaction without sufficient understanding of the impact of these small plastics.

Another element that was taken into consideration when narrowing down a research topic was relevance. Unfortunately, the impact of microplastics cannot be pinned to just one region, species, or population. In a world that has been highly dependent on plastic for decades, microplastics can be found everywhere from the peak of Mount Everest (Wilkinson, 2021) to the depths of Marianas Trench (Gibbens, 2021). As a result of the expansive existence of plastics from their overproduction and overconsumption, microplastics appear from the breakdown of these plastic materials. These plastic fragments that range between 0.1µm (micrometer) and 5mm (millimeter) spread throughout the environment and act as transmissible vectors that can facilitate the movement of chemicals and other pollutants (Campanale, et al., 2020). As a global problem with linkages to nearly every corner of the planet, there needs to be a stronger sense of urgency in not only acknowledging their accumulation in our environment, but also in seeking to understand what the impacts are and how we can prevent, adapt to, and mitigate them.

By taking a mixed methodology approach, this paper will first seek to establish the criticality of microplastics as a current environmental and health issue across the world. Following this, different routes of exposure to microplastics and their adjoining chemicals will be identified and explored, with special attention to a group of chemicals known as endocrine disruptors. Subsequently, this paper will then identify the linkages and patterns between microplastic exposure and animal and human reproductive health. This main section will also highlight previous studies on microplastics and animal reproduction and later seek to make connections between increasing microplastic exposure and decreasing reproductive abilities in both males and females. Collectively, these sections are designed to create a firm understanding of the impacts of microplastics on reproductive health through a series of varying perspectives. Finally, a range of prevention, adaptation, and mitigation strategies will be recommended to minimize exposure and curtail the current and future reproductive health impacts.

Ⅱ. Research Methodology

To conduct a comprehensive and all-encompassing analysis of microplastics and their rapport with reproductive health, a mixed-methods research approach was taken using a combination of published literature and two qualitative interviews. Specifically, this paper used the triangular mixed methods design (Almalki, 2016) to equally gather data from both qualitative and quantitative sources. This design was chosen based on the interdisciplinary nature of the research topic and the value of a balanced mixed-methods technique. With connections to global health, reproductive health, the environment, chemistry, biology, policy development, economics, and more, it was clear that exploring the topic from various field perspectives would be necessary in order to take an integrated and impartial approach.

In terms of data collection, the process began with a broad review of publications from both scientific and gray literature to develop a foundational understanding of microplastics and their function in the environment and health. Initially, the purpose of this research was to identify and analyze the impacts of microplastics on both human and planetary health, but with a deepened understanding of this topic, it was concluded that this approach was too broad. To further narrow down the problem that would be addressed in this paper, the problem statement matrix was used to look at: what the problem is, who is experiencing the problem, where the problem is occurring, and why the problem is occurring. As a wide-scale problem impacting people, animals, and the environment across the globe, it was challenging to select a specific population or geographic location where in-depth research could be best applied.

While researching the health-related impacts that microplastics pose to human and animal health, one area that seemed both significant and underdeveloped was reproductive health. At this point in the research process, it became clear that there was a lack of conclusive research on the interrelationship between microplastics and reproductive health, and thus a need for a closer look at their connection. This modification of the research objective allowed for a more in-depth analysis that helped expand upon and draw connections between the existing literature.

Academic information was sourced through the use of; online academic databases such as PubMed, JSTOR, Google Scholar, various online journals, and gray literature from the World Health Organization (WHO), Federal Drug Administration (FDA), and United Nations Environment Program (UNEP). Keywords and phrases that were utilized throughout the research process included: “microplastics”, “reproductive health”, “human health”, “animal health”, “plastic production” “plastic consumption”, “endocrine disruptors”, “chemical additives”, “microplastic degradation”, “microplastic routes of exposure”, “toxicants”, and “reproductive systems”.

Interviews

Additionally, two formal interviews were conducted to further build on the research into microplastics. The first interview was with Pierre Quiblier, the Program Officer at the Chemical and Health branch of the UNEP. With an extensive and impressive background, Mr. Quiblier played a significant role in strengthening the relationship between the WHO and UNEP through the health and environmental linkages report before narrowing his focus to chemical waste management. This in-person interview at the UNEP Geneva office lasted roughly 42 minutes and focused on the chemicals involved in the plastics industry, technologies and techniques used to assess the impacts of these chemicals, and the importance of an integrated and collaborative approach to targeting this problem. The second interview conducted was with Denise Mitrano Ph.D., an Environmental Analytical Chemist and Professor in the Department of Environmental Systems Science at ETH Zurich. Dr. Mitrano started her career in analytical chemistry by studying engineered nano chemicals that were being used in consumer products. Shortly after obtaining her Ph.D., she was completing postdoctoral research at the Swiss Material Science and Technology Institute when the topic of plastics and microplastics came to her attention. Since then, she has either written or contributed to more than 30 published research papers on the distribution and impacts of anthropogenic materials including nano- and microplastics. The interview with Dr. Mitrano took place in her office at ETH Zurich and lasted roughly 32 minutes. For this interview, several of the questions were centered around her previous work and publications on microplastics to better understand her experience. Other questions that were discussed focused on the criticality of microplastics in the scheme of climate change, the practicality of implementing policies surrounding microplastics and their adjoining chemicals, and what the most toxic chemicals involved with plastics were from her perspective. Following the formal interview, Dr. Mitrano gave a short tour of the lab that she works in at ETH and explained some of the current research her and her students were conducting.

Limitations & Challenges

As there is with all research, there were several limitations and challenges that influenced the development and outcome of this paper. First, the research presented, analyzed, and discussed throughout this paper was limited by time. As mentioned above, many accomplished scientists spend decades studying these extremely complicated and multi-faceted topics. Secondly, there was a challenge of non-responsiveness from potential interviewees throughout the process of reaching out. Finally, and as a result of the novelty of this research topic, another limitation was the finite and contradictory research on microplastics and how they impact reproductive health. To conclude, the information presented and analyzed in this paper is intended to identify a correlation between microplastics and reproductive health, as more research is necessary to confirm a causal relationship.

Ethics

It should be noted that a Human Subjects Review (HSR) for this research paper was submitted and approved by the Local Research Board (LRB) at the start of the research process. Appropriate ethical guidelines were taken into consideration and necessary protocols were adhered to. As no vulnerable populations were directly identified or included throughout the research process, there were very few ethical hurdles. Lastly, the two interviews included in this paper were conducted, recorded, and transcribed after both oral and written consent was obtained.

Ⅲ. Literature Review

As a problem just recently introduced and recognized across all disciplines, the bulk of literature on microplastics is from the last two decades. As such, the vast majority of current literature on microplastics focuses on the lifecycle of microplastics and determining the prevalence of these micro-materials throughout our environment and bodies. Generally, research on this topic is directed at the identification of the issue and environmental impacts, as opposed to the impacts on health. This is in part because the academic community is still trying to understand the full extent and nature of microplastic pollution, and in part, because it is far easier to gather data from the environment and conduct experiments on animals than it is with humans. Another reason for the lack of conclusive research on microplastics and their implications is their complexity. Not only do these small fragments serve as vectors of chemical transport throughout the environment, but they also pose a chemical issue known as the “cocktail effect”. This effect, which will be discussed further in the section on chemicals, is a direct result of the combination of different contaminants with chemical additives.

Articles that proved very helpful in developing a foundational understanding of microplastics and their function in our lives include those from (National Geographic Society (NGS), 2019), (Kannan & Vimalkumar, 2021), (World Wildlife Foundation (WWF), 2019), and (UNEP, nd.). While very informative, these materials lacked a critical perspective and failed to explore the depth of the problem or which specific chemicals are used in the production of plastics.

To strengthen this knowledge gap, two interviews were conducted with experts who have strong, yet distinctive backgrounds in chemistry. Before carrying out these interviews, extensive research was conducted on the chemical makeup of microplastics with sufficient information acquired from (National Research Council, 1994), (Campanale et al., 2020), (Plastics Europe, 2022), and (CDC, 2021). Together, these sources provided strong scientific information that enhanced the chemistry component of this paper.

Both interviews offered different perspectives and brought new current theories to light. The interview with Mr. Quiblier brought up the issue of the "cocktail effect" and provided further insight into what challenges arise when trying to assess who, what, and how certain chemicals impact health. The interview with Dr. Mitrano also provided new information, with a focus on the plastic life cycle and how policy measures had the potential to create change. Unfortunately, neither Mr. Quiblier nor Dr. Mitrano has a strong background in the reproductive health-related impacts of these chemicals as their work is more directed toward management and laboratory studies.

To create the link between chemical exposure and reproductive health, a large number of laboratory studies on exposed animals were collected and assessed, including those from (Bhagat, et al., 2020), (Wang et al., 2021), (Deng et al., 2017), (Zantis et al., 2020), (Sussarellu et al., 2016), (Semenza et al., 1997), (Tyler & Jobling, 2008), and (Schöpfer et al., 2020). While the evidence from these studies varied in strength, it was imperative to take a wide approach by looking at several species and endocrine disruptors to identify concrete patterns. Additionally, it was important to fully understand the scope of each publication and what limitations ensued. For example, most of the studies were carried out on a singular species, making it difficult to interpret how other reproductive systems might respond. Other animal studies were excluded from the final paper because the methodology used to obtain results was questionable.

One piece of literature that was exceptionally resourceful throughout the search process was Dr. Shanna Swan's book, *Count Down: How Our Modern World Is Threatening Sperm Counts, Altering Male and Female Reproductive Development, and Imperiling the Future of the Human Race*. Her success in distilling data from hundreds of published studies and drawing coherent conclusions served as a strong base point for the analysis of this topic. Moreover, her team's research is the first to explore the connection between anogenital distance (AGD) in humans, chemical exposure, and male fertility (Swan et al., 2005) (Swan et al., 2015). While these studies support other data suggesting that microplastics are impacting reproductive health, it should clearly be stated that additional research on humans is necessary to confirm this relationship.

Ⅳ**. Analysis**

Criticality and Causation

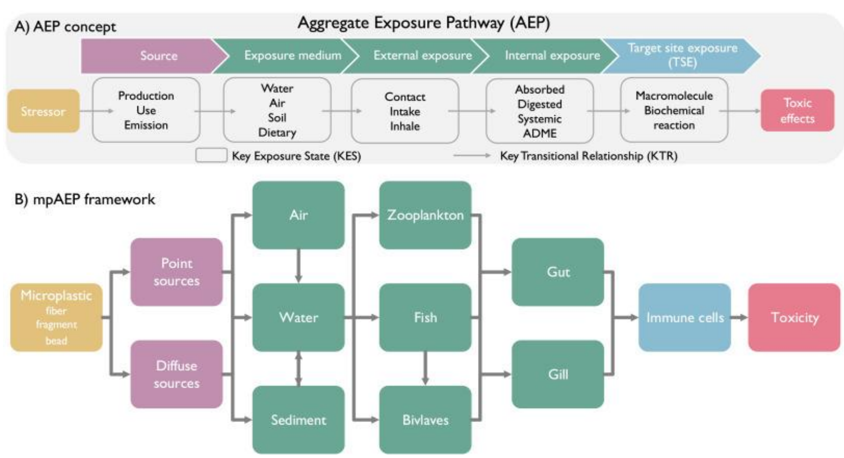
The criticality of microplastics and their impact on both the environment and humans are not to be overlooked or underestimated. The annual global production of plastics has exponentially increased since the 1950s, when it was roughly 2 million tons per year, to today, where we produce over 380 million tons of plastic waste annually (Ritchie & Roser, 2018). Of all the plastic waste ever produced, less than 9% has been recycled, roughly 12% has been incinerated, and the remaining 79% has accumulated in the environment and landfills (UNEP, n.d.). If we continue to produce, use, and dispose of plastic in the same manner that we have for the past 7 decades, it is estimated that there will be over 12 billion tons of plastic waste in the environment, landfills, and our bodies by 2050. Despite this alarming reality, the global plastic market has continued to grow into one of the world's most lucrative industries. As of 2020, the market stands at a value of approximately $579.7 billion and is projected to reach a value of $750.1 billion by 2028 (Tiseo, 2021).

Microplastics can be broken down into two categories: primary and secondary (NGS, 2019). Primary microplastics refer to the small particles that are specifically designed for commercial use. This category encompasses microbeads, which are manufactured polyethylene plastics used in various beauty products for exfoliating purposes, and microfibers, which are released from textiles such as clothing, rugs, and cigarette butts, among others. Secondary microplastics are the fragments of plastic that break off larger pieces of plastic through exposure to environmental stressors such as UV exposure and wind. Through the process of continual weathering, objects like plastic bags, toys, tires, and water bottles slowly break down and release millions of microplastic particles into the environment.

Exposure

Most of our daily activities have evolved to center around plastic use and as a result of this lifestyle, we are ingesting plastic particles and their related chemicals every day (Kannan & Vimalkumar, 2021). Researchers have found that in just one week, the average human consumes at least 5 grams of plastic which is equivalent to the weight of a credit card. In one year, a human consumes at least 250 grams of plastic, comparable to the weight of a dinner plate. Finally, over the course of an average lifetime of ~79 years, it is estimated that a single person has consumed around 44 pounds of plastic, the equivalent weight of two large recycling bins or a medium-sized dog (WWF, 2019). Further illustrating that human exposure is constant, a recent study from 2021 found that in drinking 100mL of a hot liquid (coffee or tea) from a disposable paper cup, an average of 25,000 micron-sized plastic particles are also ingested (Ranjan et al., 2021). These channels of exposure are everywhere and thus impossible to completely avoid.

Existing studies have concluded that the three primary pathways in which animals and humans are exposed to microplastics are: inhalation (Kannan & Vimalkumar, 2021), food ingestion (Kwon et al., 2020), and water consumption (WHO, 2019). Below is a recently published pathway framework designed specifically for microplastics. This holistic approach for exposure assessment successfully “links a cascade of causally related key exposure states (KESs), such as source, exposure medium, external exposure, internal exposure, and target site exposure (TSE) of a chemical by their key transitional relationships (KTRs) into a pathway or pathway network” (Peng et al. 2022). In the context of this research paper, the graph provides an organized visual representation of the different exposure pathways to aid understanding and emphasize the importance.



Aggregate Exposure Pathway Graph

At this point, it is well established that humans and animals are constantly exposed to microplastic particles through a plethora of pathways. While this concept is relatively straightforward, the impact of microplastic exposure on animal and human health is less understood. In an interview with Mr. Quiblier of the UNEP, the recent publication that microplastics have been found for the first time in human blood (Carrington, 2022) was brought up in conversation. When asked about his reaction to that news, Quiblier responded: “What is the impact on our blood? Some would say, you know if it’s null, it's fine…how well can we digest [them]?... if correlations can be found with a set of cancer that is growing suddenly, [then] epidemically that is of great concern” (Quiblier, 2022). The same can be said for all of the previously discussed information when looking at reproductive health. What are the impacts of microplastics on reproductive health? If there aren’t any, then why does it matter? While the physical plastics themselves may not pose a significant threat, the chemicals that make up the particles are linked to various health-related issues. In the next sections, these chemical compositions of microplastics will be further discussed along with the health-related consequences of constant exposure.

Microplastics & Chemicals

When considering the toxicity of different microplastic particles, the “size, shape, chemical composition, surface charge and hydrophobicity” (Kannan & Vimalkumar, 2021) all need to be taken into consideration. To address individual chemicals involved in the process of producing and consuming plastics would require an inordinate amount of time and resources. Furthermore, identifying exactly which chemicals are causing reproductive health issues poses an even more complicated challenge. As previously mentioned, there is growing concern around a phenomenon known as the cocktail effect. When Mr. Quiblier was asked to share the most surprising or alarming piece of information he has encountered over the course of his career, he immediately brought up the cocktail effect of chemicals:

> “I was very stunned by this notion of chemicals and mixtures that is jeopardizing our best assessment capacities…we always respect science because it’s always assessing and providing solutions and understanding [but] here, you have our best scientists tell[ing] you, you know, we absolutely don’t know how to measure that, how to do that” (Quiblier, 2022).

He further explained that scientists understand how chemicals react under “a certain set of conditions”, but when you introduce an unfamiliar mixture of chemicals under different temperatures or in different environments, it becomes much more difficult to assess. As pointed out by Dr. Mitrano,

> “there are many particles which are naturally existing in the environment, and so scientists must now assess what is different about microplastic compared to other natural or anthropogenic particles, and what hazards can be associated with plastics, either from the polymer itself or from plastic added chemicals".

With these challenges in mind, this section will give a brief overview of the chemicals involved in microplastics before further focusing on the group that affects reproductive health.

The chemicals that constitute microplastics can be broken down into two main categories: “additives and polymeric raw materials originating from the plastics, and chemicals absorbed from the surrounding ambiance” (Campanale et al., 2020). By definition, plastic materials are simply a compound of polymers plus additives that can be shaped or molded into everyday products (National Research Council, 1994).

Raw materials of polymers are the monomers that together form the base structure of plastics. The monomers that make up the polymers for plastic are derived from natural materials such as coal, natural gas, and crude oil. From here the monomers, such as ethylene and propylene, go under specific processes called polymerization and polycondensation that link them together, creating longer chains called polymers (Plastics Europe, 2022). Along with the raw materials of polymers are the chemical additives. Additives are various chemical substances that are added to the organic polymer chains to maintain, enhance, and impart specific characteristics to the plastic (Wiesinger et al, 2021). For example, phthalates, also known as plasticizers, are a group of chemical additives that make plastics more durable (CDC, 2021). Similarly, bisphenol A (BPA) is an industrial chemical used to make polycarbonate plastics as well as epoxy resins (FDA, n.d.) which are used extensively in the food industry. While more research is necessary to confirm the health-related impacts that some of these additives have on humans, there has already been sufficient evidence suggesting that phthalates impact the reproductive system in animals (CDC, 2021) and that BPAs are toxic to both the reproductive and developmental systems (Ohore, Zhang, 2019).

The second category of chemicals that constitute microplastics are the organic and inorganic chemicals that are absorbed or adhered to them, resulting in a more hazardous and toxic particle. In contrast to larger pieces of plastic, "the surface area-to-volume ratio of microplastics is large, making them a good sorbent for toxic chemicals such as heavy metals and organic chemicals, i.e. POPs loading on its surface. Therefore, it acts as a "conveyor of contaminants to organisms and between environment media" (Verla et al., 2019). "Consequently, multiple stressors may have a larger cumulative effect than any one individual stressor, but scientists are just beginning to evaluate how plastics impact the environment when in the presence of other pollutants" (Mitrano, 2022). Although the number of chemicals that fall under the umbrella of persistent organic pollutants (POPs) is large, the most commonly encountered POPs are organochlorine pesticides and dioxins (WHO, n.d.).

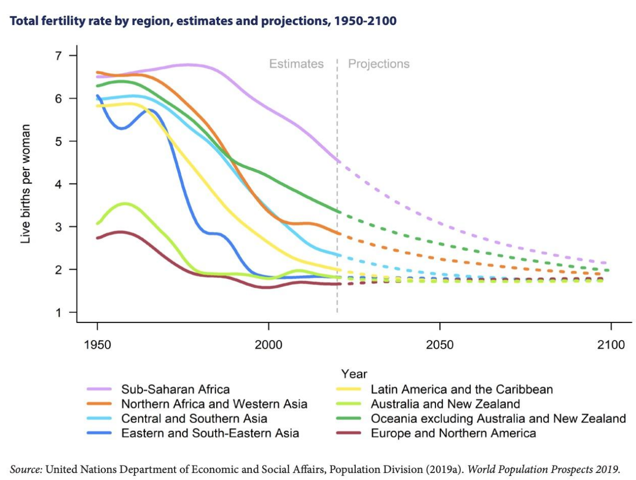
In recognition of the adverse effects that these chemicals have on human health and the environment, a treaty known as the Stockholm Convention was created to reduce the production and release of the twelve most worrisome POPs, also known as the "dirty dozen". However, as pointed out by UNEP Mr. Quiblier, "this is just the tip of the iceberg…we limited our attention to only a few [POPs] in comparison to the number of chemicals that are produced which goes to more than 700,000" (Quiblier, 2022). From a policy development standpoint, the Stockholm Convention is considered a success with 185 parties agreeing to stricter regulation of 28 POPs in their production and use (Stockholm Convention, 2019). However, upon further investigation into the registries of specific exemptions, it becomes clear that several of the involved countries are still producing and using these chemicals, often in unknown quantities (Stockholm Convention, 2019). Further noted by Dr. Mitrano, "Regulations are only as good as long as they are enforceable, and they are enforceable only as long as they are measurable" (Mitrano, 2022). Without significant collaboration between all sectors involved in the production and consumption of plastics, the tangibility for meaningful change is unlikely.

Trends in Human Reproductive Health

By definition, reproductive health refers to "the condition of male and female reproductive systems during all stages of life" (NIEHS, 2021). Trends in reproductive human health can be monitored and examined using a wide range of indicators, with the most common being: total fertility rate (TFR), contraceptive prevalence, and maternal mortality rate (MMR). To get an overall sense of how trends in both female and male health have evolved, this section will use graphs indicating TFR and sperm count to demonstrate these changes.

Total Fertility Rate

Arguably the most useful indicator for measuring overall fertility health is the TFR. This method of measurement provides a "ratio of annual births to women at a given age or age-group to the population of women at the same age or age-group, in the same year[s], for a given country, territory, or geographic area"(WHO, nd.). Undeniably, this number has fallen dramatically over the past five decades in most countries across the world. The chart below from the UN shows just how significant this drop in fertility rate is, how it is projected to continue and demonstrates that this phenomenon is global.

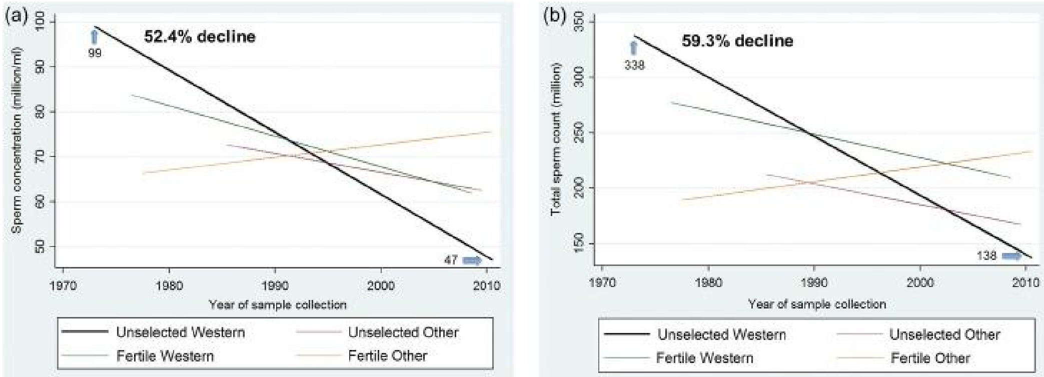


Total Fertility Rate by Region (1950-2100)

There are a significant number of factors that are understood to influence fertility rates across the world including cultural norms, socioeconomic status, education status, and access to family planning. However, only in recent years has it been considered that environmental exposures such as those from microplastics play a role. The possibility of a connection between these has swiftly become an important focus for the public health sector to look at with a critical lens.

Sperm Trends

The second indicator that will be used to express trends in reproductive health is sperm count and concentration. Although less commonly used when analyzing reproductive health trends, the concentration of sperm in semen is a strong indicator of male fertility in humans. Sperm count is measured by looking at the concentration of sperm within a certain sized sample of semen. Currently, there is no source of data that observes patterns in sperm count on a global scale, however, these shifts can be observed in western men. Dr. Shanna Swan and a team of researchers recently took on the task of examining over 7,500 studies on sperm patterns in semen to observe and compile the data into two graphs. In their research, they chose to separate western and non-western studies because there was insufficient data from non-western studies to represent such a large portion of the world. Furthermore, they separated data from western studies into fertile men (selected), and men who did not have prior knowledge of their fertility (unselected). By doing this, they successfully compiled enough data to create two meta-regression models showing a clear decline in both sperm concentration and total sperm count in western countries from 1970 to 2010. Below are the aforementioned graphs showing (a) the data for sperm concentration and (b) the data for total sperm count (Levine et al., 2017).



Sperm Concentration and Count (1970-2010)

In the context of this paper, the most important takeaway from this study is that sperm count and concentration are declining at a concerning and steady rate. Both somber and undeniable, the graphs produced here along with a second meta-analysis from 2017 suggest that by 2045, the median sperm count will have reached zero (Levine et al., 2017). This would mean that "most couples may have to use assisted reproduction" (ART) if they want to have children (Corbyn, 2021).

While these graphs only chart sperm count and concentration, it is necessary to note that sperm is only one measure of reproductive health and that there are many more. Some other reproductive health issues relevant to men include short AGD, small penis and scrotum, reduced testosterone, and gentital birth defects (Collaborative on Health and the Environment (COHAE), 2021). For females, reproductive problems include low birth weight or prematurity, menstrual problems, endometriosis, premature egg depletion, early puberty, and miscarriage (COHAE, 2021). Additionally, there are reproductive health problems that impact both men and women. These include infertility, ambiguous genitalia, hormone abnormalities, low libido, DNA damage in sperm and egg, and ART failure (COHAE, 2021).

Endocrine Disruptors

When considering possible causes for shifts in reproductive health, two overarching categories emerge; genetics and the environment. While genes certainly influence reproductive health in both males and females, the rate of change within the last few decades suggests that something larger than genetics is at play. With a deeper look into environmental factors influencing reproductive health, this category can be further broken down into chemical exposures and lifestyle factors. Lifestyle factors such as diet, exercise, and smoking are confirmed to have an impact on reproductive health (Sharma et al., 2013), but do not single-handedly account for these dramatic shifts (Fischer, 2021). Furthermore, it should be clarified that lifestyle factors directly influence individual and societal exposure to chemicals. For example, someone who often eats food sourced from the ocean is likely consuming a greater amount of microplastics, and thus the chemicals in and attached to them. Similarly, someone who frequently works with chemicals in a lab will also have higher rates of exposure than someone who works in an office. The time and resources required to analyze individual chemical exposures are beyond the scope of this research project and would require significant resources. While lifestyle factors are a critical aspect of reproductive health, this paper is intended to focus on chemical exposure, and more specifically, endocrine disruptors. In large, the impacts of chemicals on health should not be overlooked when considering the relationship between microplastics and overall health.

However, when specifically analyzing reproductive health, one category of chemicals stands out: endocrine disruptors. Endocrine-disrupting chemicals include phthalates, bisphenols, perfluoroalkyl and polyfluoroalkyl substances (PFAS), pesticides, and flame retardants. Individually and in combination with other chemicals, these substances can interfere with the normal functions of the endocrine system. Exactly how these chemicals interfere with hormones varies depending on the type and dose. After being absorbed into the body, they “can decrease or increase normal hormone levels, mimic the body's natural hormones, or alter the natural production of hormones” (NIEHS, 2022). In large, the existing studies and literature on how microplastics and endocrine-disrupting chemicals impact reproductive health have focused on animals. This is because it is easier to study smaller organisms and the nature of the research topic makes it difficult to enroll humans in studies while adhering to ethics regulations. While the impacts on reproductive health have been more widely studied on animals than on humans, trends in human reproductive health suggest that they are not the only ones affected. The next section will discuss some of the published research on animal exposure to endocrine-disrupting chemicals and what it means for their reproductive health, before shifting the focus back to humans.

Animal Reproductive Health

The Great Pacific Garbage Patch is one of the best-known examples of concentrated plastics in the world today. With a surface area of roughly 1.6 million square kilometers, these islands of trash cover an area equivalent to three times the size of France (Lebreton et al., 2018). As a result of this growing problem, marine wildlife is often experiencing the first noticeable impacts of microplastic exposure. Analyses of wild zebrafish (Bhagat, et al., 2020), seabirds (Wang et al., 2021), mice (Deng et al., 2017), and cetaceans (Zantis et al., 2020) all showed a notable buildup of microplastics in their biological systems. Along with inflammation, unusual metabolic and enzyme activity, and intestinal damage, (Bhuyan, 2022), this buildup of microplastics increases their exposure to endocrine disruptors. In terms of reproductive health, these studies show significant and irreversible consequences.

Two animal studies will be discussed to demonstrate these consequences in different organisms. The first study, conducted in France and published in 2016, looked at how oyster reproduction was impacted by exposure to polystyrene microplastics (Sussarellu et al., 2016). Over the course of two months, Pacific adult oysters were continually exposed to two different-sized microplastics. Observations on consumption, absorption, structural growth, and larval development of offspring from both the exposed and unexposed groups were taken following the two-month period. Their results found that the exposed group experienced a "23% reduction in sperm velocity", "increased stress and demand to maintain homeostasis", and reduced oocyte (immature egg) quantity and size "(−38% and −5%, respectively)" in the exposed adults (Sussarellu et al., 2016). Furthermore, "strong negative effects were shown on broodstock fecundity and offspring growth at larval stages"(Sussarellu et al., 2016).

The second study looked at nematodes, or roundworms, which are very small worms between 50µm in diameter and 1 mm in length (Ingham, nd.) that play an important role in the soil food web. This study exposed nematodes to two different types of plastics: (1) a low-density polyethylene (LDPE) in the form of granules and (2) a blend consisting of the polymers polylactide (PLA) and Polybutylene adipate-co-terephthalate (PBAT) over a period of six days (Schöpfer et al., 2020). For context, LDPEs are used for products like shrink wrap and plastic bags (Omnexus, nd.) while PLA/PBAT is a biodegradable blend used to make 'eco-products' like straws and containers (Sulzer, nd.). After the reproductive phase, the surviving nematodes were examined and findings were recorded. In their results, they found that "under MP exposure, nematodes had fewer offspring (as low as -22.9%) compared to nematodes in the control group. This decline was independent of the plastic type. We detected a tendency toward greater decreases in offspring at higher concentrations" (Schöpfer et al., 2020). In tandem, these studies provide specific examples of how the reproductive health of organisms at the bottom of the food chain can be impacted by microplastic consumption and exposure in controlled settings.

Other examples of adverse reproductive health effects that have been well established in animal studies include egg-thinning in birds from dichloro-diphenyl-trichloroethane (DDT) exposure (Kolaja & Hinton, 1997), imposex, or the "superimposition of male-type genital organs (penis and *vas deferens*) on female" gastropods (Horiguchi, 2006) from organotins (Barroso et al., 2002), feminization in male fish from endocrine disruptors (Tyler & Jobling, 2008), and impaired reproductive development along with abnormalities from chemicals including DDT (Semenza et al., 1997). In the wildlife impacts section of the Global Chemicals Outlook published by the UNEP and coordinated by Pierre Quiblier, it is further confirmed that:

> "these contaminants cause a variety of diseases and disorders—including cancers, alterations in sexual development, neurological dysfunction, and reproductive failure—and in the case of organochlorine chemicals, such as PCBs and DDT, have been responsible for the near extinction of some species" (UNEP, 2013).

In the interview with Mr. Quiblier, this topic was discussed in the context of humanity. Specifically, a question was set up to first establish the scientifically recognized relationship between microplastic chemical exposure and animal reproductive health, then project this relationship onto the fate of humanity. The overarching question posed to Mr. Quiblier was: "how possible do you think it would be for microplastics and their chemicals to bring humans to the brink of extinction?" (Quiblier, 2022). After a deep sigh and time to think, his response began with "there is a threat. There is a threat here" before shifting the focus of the discussion to how this “threat” can be minimized or even prevented (Quiblier, 2022). As shown with the help of various animal studies, the Global Chemicals Outlook, and a prudent remark from Mr. Quiblier, endocrine-disrupting chemicals found in microplastics have the potential to disrupt reproductive health, and thus reproduction as a whole.

Male Reproductive Health

One of the most comprehensive and noteworthy publications looking into this declining sperm concentration and count along with other reproductive issues is from Dr. Shanna Swan, a reproductive epidemiologist at the Icahn School of Medicine at Mount Sinai, New York. Her extensive research on the relationship between endocrine disruptors and reproductive health resulted in her and Stacy Colino’s book *Count Down*, published in 2020. In chapter 2 of this book, Swan takes a close look at the role of anti-androgens, a group of chemicals that are found to interfere with testosterone levels in men. Specifically, her focus is on phthalates, or plasticizers, which are the largest and most prevalent class of these chemicals. As explained, phthalates are added to everyday plastic products to increase their durability, making them a common chemical in many microplastics. Numerous animal studies have demonstrated that if an expecting mother is exposed to phthalates after copulating, her offspring will have lower levels of testosterone, smaller or malformed penises, undescended testicles, and shortened AGDs (Foster et al. 2000). An established indicator of infertility, low sperm concentrations, and low sperm count (Eisenberg & Lipshultz, 2014) (Mendiola et al., 2011) (Mitchell et al., 2015), AGD is the measurement from the base of the penis to the anal opening. An important study from 2000 looked directly at this measurement in rats and how it was impacted by phthalate exposure in utero. Their data found that AGD, a marker of sexual differentiation, was reduced by an average of 36% in male rats who were exposed during a critical stage of reproductive tract development

(Parks, 2000). These associated genital differentiations with phthalate exposure were so groundbreaking that it justified the creation of an entirely new condition, the “phthalate syndrome”.

Inspired by the results of this study, Swan was interested in carrying out research to bridge the gap between animals and humans. To do this, she first took urine samples from to-be mothers at several stages during pregnancy and submitted them to the CDC for urinary phthalate metabolite analyses. After giving birth, her team reached out to the mothers who had sons and took measurements that included AGD, scrotal size, penile width, testicular descent, and weight of the infant boys (Swan et al., 2005). With support from in-depth regression, categorical, and statistical analyses, this study along with a second one conducted in 2015 (Swan et al. 2015), concluded that “prenatal phthalate exposure causes the phthalate syndrome in human males", “phthalates are antiandrogenic endocrine disruptors”, and that “AGD is a marker of fetal androgen exposure” (Swan COHAE, 2021). Other studies on how microplastics and their adjoining chemicals are suspected to influence male reproductive health have looked at urinary BPA levels, semen quality, and sperm DNA integrity (Omran et al., 2019), providing similar results that suggest a correlation with exposure (Pollard et al., 2019). While evidence regarding the toxicity of microplastics and what it means for male reproductive health is still emerging, trends in human sperm quality, animal exposure models, and research provided by Swan et al. all suggest that the male population is already being impacted by perpetual microplastic exposure.

Female Reproductive Health

While it is important to explore how microplastics are impacting reproductive health in animals and men, the full picture of reproductive health includes women. As shown in the TFR graph, the number of total births per woman is dropping at an alarming rate. In fact, “in 2017, the total birth rate for women in the United States was 16 percent below what is considered necessary for our population to replace itself over time" (Swan & Colino, 2020). There are likely numerous reasons for the declining fertility rate including a rise in obesity, an increase in sexually transmitted diseases, lack of affordable housing, and other socio-economic factors (Nargund, 2009). Additionally, there are concerns that the additives used in plastic, along with the POPs that attach themselves to microplastics are playing a role in these record birth declines. Again, the attention falls on endocrine-disrupting chemicals. The development, function, and health of the female reproductive tract are very sensitive to hormonal changes. Regular exposure to microplastics in turn means regular exposure to their adjoining endocrine-disrupting chemicals and organochlorine substances. Some of the strongest research into how endocrine disruptors impact reproductive health looked at the first synthetic form of estrogen, diethylstilbestrol (DES), which was routinely prescribed to women in the mid-1900s to prevent miscarriages and pregnancy complications. Years later, studies on the daughters of women who had been given DES found that exposure to the drug in utero was strongly correlated to at least 12 medical conditions (NIH, 2015) including menstrual irregularities, altered uterine structure, infertility, miscarriage, premature births, breast cancer (Nicolopoulou-Stamati & Pitsos, 2001), and a rare cancer, known as adenocarcinoma of the vagina (Herbst et al., 1971). Moreover, "endocrine alterations in women resulting from environmental or occupational exposure may represent increased risk for endometriosis, reproductive and other endocrine-related cancers, or impaired oocyte competence, ovarian function or menstrual cycling" (Meeker et al., 2009). This cause and effect observed between endocrine disruptors and unfavorable reproductive health outcomes undeniably raises concern for future generations of women's health.

Ⅴ. Recommendations

To make a considerable change in the global plastic crisis, an integrated approach using preventative, mitigative, and innovative methods needs to be seriously considered. The criticality of this issue and time-sensitive impacts means that microplastics can no longer be placed on the back-burner of the global agenda. Currently, there is no singular measure that will solve the problem of microplastics or their associated impacts on reproductive health. With this in mind, this section will briefly recommend different approaches to curb the exposure, consumption, and production of microplastics. It should be reiterated that taking just one approach will not resolve this omnipresent problem. One of the most important channels for creating sustainable and widespread change is education. Generally speaking, the overarching topic of microplastics is not addressed at any point in education, nor do many people understand how far-reaching and interdisciplinary the matter is. Consequently, a large portion of the public underestimates how microplastics and their adjoining chemicals serve as both environmental and health stressors. Taking simple steps toward educating current and future generations on microplastics and their impacts is just one of many measures that could alleviate this problem. Another recommendation to consider is taking harm reduction measures to limit daily exposure to microplastics. Although this is difficult considering the certainty that microplastics have permeated every ecosystem in the world, there are still simple actions that can curb the extent of exposure. Such personal measures include, but are not limited to, filtering tap water, avoiding plastic containers, avoiding products with microbeads, and limiting meat and fish consumption. While these behaviors are certainly proactive in the war against plastics, Dr. Mitrano accurately pointed out that "in order to solve the plastic environmental crisis, a combination of targeted policies and technological advances will be more effective, especially when they consider the entire life-cycle of plastics"

(Mitrano, 2022). At the center of sustainability challenges, it is crucial to include and oblige all sectors in decision making, if a momentous long-term change is going to happen.

All of these aforementioned recommendations may alleviate the current and future impacts that microplastics and their adjoining chemicals pose to reproductive health and our environment, but it should also be reminded that the global ecosystem has already been deeply exposed and that these particles are difficult to remove. A handful of methods that are currently being explored include bacteria-eating plastics (Xia et al., 2019), electrocoagulation processes (Shen, et al., 2021), and different wastewater treatment systems (Vuori & Ollikainen 2021). All in all, continued efforts toward prevention, mitigation, and detoxification will be necessary in order to clean up the mess that's been made. Having only mentioned a handful, there is an assortment of other approaches that can be taken towards preventing and minimizing the impacts of these plastics and chemicals. Questions surrounding the efficacy and plausibility of these various approaches suggest that further research would be advantageous in making progress.

VI. Conclusion

If we do not acknowledge and address this problem as a global issue in the next few years, the bioaccumulation and biomagnification of microplastics and their adjoining chemicals in humans, animals, and the environment may result in devastating and irreversible impacts. As this paper observed, there are notable negative impacts that microplastics pose to reproductive health in animals and humans. This connection was supported through the identification of reproductive trends such as TFR and sperm count, a detailed breakdown of the chemical makeup of microplastics, and several animal and human studies observing the effects of endocrine-disrupting chemical exposure. The implications of this information are extremely relevant to the field of global health and open up numerous possibilities for further research.

Although this paper provides significant evidence suggesting a relationship between microplastics and negative reproductive health outcomes, there is a significant need for increased attention and further research into microplastics, endocrine disruptors, reproductive health, prevention, and a combination of the four.

Ⅶ. Abbreviation List

AGD= Anogenital Distance

ART= Assisted Reproductive Technology

BFA= Bisphenol A

CDC= Centers for Disease Control

COHAE= Collaborative on Health and the Environment

DDT= Dichloro-Diphenyl-Trichloroethane

DES= Diethylstilbestrol

DNA= Deoxyribonucleic Acid

FDA= Federal Drug Administration

HSR= Human Subjects Review

KES= Key Exposure States

LDPE= Low-Density Polyethylene

LRB= Local Research Board

MMR= Maternal Mortality Rate

NGS= National Geographic Society

NIEHS= National Institute of Environmental Health Sciences

PFAS= Perfluoroalkyl and Polyfluoroalkyl Substances

PLA= Polylactide

POPS= Persistent Organic Pollutants

TFR= Total Fertility Rate

TSE= Target Site Exposure

UNEP= United Nations Environmental Program

WHO= World Health Organization

WWF= World Wildlife Foundation

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