Literature Review of the Effects of Microplastics on the Health of Marine Organisms.

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Table of Contents

Content	Page Numbers
Acknowledgments	3
Abstract	4
Introduction	5-7
Methods	8
Expected and Alternative Outcomes	8-9
Results and Discussion	9-21
References	22-27

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Abstract

Littering of plastic is quickly becoming the cause of a noteworthy ecological contamination. Microplastics pose significant threat towards marine health and threaten the stability of the oceans and the food chain. Accumulation and degradation of plastic particles in the marine ecosystem causes damage to various aquatic organisms, both plants and animals by interfering in vital processes such as reproduction, digestion, and photosynthesis. The aim of this study was to examine the effects of microplastics on the health of marine water organisms through a literature review. By reading scientific papers in the primary literature, the effects of microplastics on marine health were studied.

Results obtained in various scientific experiments, statistical data presented in the literature as well as conclusions drawn by scientists in the field were studied to better understand the negative consequences of microplastics in marine ecosystems. Accumulation and translocation were found to be the fundamental routes that permit side effects of microplastic to occur. Furthermore, factors including size, density and shape were found to impact the movement of microplastics within marine ecosystems. Substantial negative health impacts on the vital systems of marine organisms including endocrine, circulatory, reproductive and digestive systems were observed. Lastly, insufficient scientific data studying the movement of microplastics through trophic levels and subsequent toxicity by bio magnification was found.

Introduction:

With increasing population, waste production and increase of plastic deposition in marine environments have skyrocketed. Within a decade the average global plastic demand has initiated a production of 245 million tones of plastic annually. Out of this mass-produced plastic, beach litter and other plastic introduced in land environments alone contribute to 80% of the plastic pollution observed in marine ecosystems (Andrady, 2010). Littering of plastic is fast becoming a major environmental pollution cause (Lambert, 2015). Plastic litter have high resistivity to weathering, erosion and degradation; be it chemical, mechanical or biological (Zbyszewski, 2010). This allows the plastic to accumulate long enough to degrade into micro and nano particles. Plastic debris at micro and nano levels have spread far and deep into the marine ecosystems (Wright, 1987).

According to the National Ocean Service, micro plastics are minute plastic particles that measure less than 5 millimeters in length (NOAA,2016). Due to this small size, micro plastics can be ingested by aquatic life, creating unknown threats to their health (Wright, 1987). Previous studies have shown that microplastics have the ability to absorb organic contaminants from their environment, causing them to become even more harmful to marine health (Lambert, 2015).

Microplastics can either cause physical injuries or serve as vectors by transporting contaminants via ingestion of chemical contaminants (Lambert, 2015). Either way, microplastics pose a significant threat towards marine health, and threaten the stability of our food chain.

Through the literature, it is clear that a significant amount of information about the effects of microplastics in marine ecosystems is still unclear. Even though progress has been made in the field to better understand the significance of micro plastic contamination, fundamental questions such as the long-term effects of micro plastics and their fate in marine

ecosystems remains unclear. It has been observed that these particles are present in not only large water bodies but are vastly distributed and present in our water column (Cole, 2010). These basic questions have been difficult to answer through research due to both this widespread property of microplastics as well as a great variation in the size and density of microplastic particles in various water systems.

Furthermore, another hindrance is the availability and necessity of different sampling methods used by researchers (Cole, 2010). Since multiple sampling methods are used, it is difficult to find a systematic format to compare and cross question multiple studies in order to draw realistic long-term conclusions (Cole, 2010). Research and review of the literature allows us to understand the properties and sources of mircoplastics, learn the routes and processes that introduce microplastics to the marine environment, study the various procedures that can detect micro plastics in the water systems, assess trends of micro plastic contaminations both spatially and temporally and better understand the impact of microplastics on the environment in terms of marine health and ecosystem pollution (Cole, 2010).

Disposal of waste and litter around marine territories is found to be the primary cause of plastic pollution in water. Litter contributes to over 80% of the plastic contaminants found in marine ecosystems (Cole, 2010). Almost half of the world's population lives within eighty kilometers of a marine ecosystem. This significantly increases the potential of plastic contaminants to enter the water systems by either direct deposition or transportation through natural agents such as wind. Furthermore, drainage systems, sewages, and industrial waste-water treatment sludge trap microplastics and serve as an introductory pathway into local marine ecosystems (Cole, 2010).

Commonly used methodology and statistical testing applied in the field of plastics and marine biology such as immunohistochemistry, transmission electron microscopy, fourier transfrom infrared spectroscopy, BPA test kit, Estrogen Elisa kit, embryotoxicity assay etc. have been used in experiments on micro plastics throughout the literature (Bosnjak, 2013). The use and effectiveness of these methods depends on the properties of the particles collected, particularly particle size. Coarse filtration is done in order to segregate the microliter from collected samples (Andrady, 2010).

However, based on the size and density of the micro-litter, the ideal method is established. For microplastics, Fluorescent technique micro spectroscopy is the ideal method of isolation (Andrady, 2010). Statistical analysis is conducted using various procedures, some of which include (multiple) Linear regression, Kruskal−Wallis etc. (Besseling et al., 2014). Other tests such as Bartlett test for homogeneity, mean, the standard deviation and paired t-test are also used (Bosnjak, 2013). Similar to the method selection, ideal statistical analysis profile is selected based on the overall objective of the research.

This study aims to better understand the harmful effects of microplastics such as, but not limited to, BPA and polystyrene on the health of marine organisms through a literature review. Through this goal, I anticipate shedding light on the impacts of microplastics on general marine wellbeing and the centrality of this result. Research in the field of microplastics pollution remains unclear, especially on the impacts of compounds such as BPA on multiple aquatic species. This literature review hopes to contribute towards this field by exploring this unclear phenomenon.

Method:

This study was conducted through an extensive scientific literature review. The results are an accumulation of published scientific data obtained in experiments and studies conducted within the field by experts around the globe. The following steps were conducted in order to study the effects of microplastics in the marine environment:

- Basic reading and research was conducted using primary and secondary literature sources such as textbooks, websites, journal articles and news articles to better understand microplastics and their impact in the environment.
- Once this fundamental research was accomplished, scientific literature and multiple sources of information were compiled.
- Based on the readings and research, conclusions were drawn about the effects of mircoplastics on marine health.
- Subsequent correlations and predictions were drawn about the fate of marine systems and their organisms in the future.

Some of the commonly used databases for research included PubMed, MEDLINE, Natural Science Collection, Earth, Atmospheric and Aquatic Science, GreenFILE, TOXLINE, Google Scholar and National Center for Biotechnology Information (NCBI).

Expected and Alternative Outcomes:

The hypothesis for this study was to find trends related to reduced physiological responses such as poor neuromuscular, reproductive, endocrine, digestive and cardiac functioning in the marine water organisms in the presence of microplastic accumulation. I also

expected to discover accumulation and toxicity of microplastics in the water as well as within the organism's vital organ systems.

Another outcome that was expected was increased translocation rates of microplastics both within the water system as well as through the organisms' bodies. Through these results I expected to draw probable causation and correlation between microplastic toxicity and poor aquatic health as well as make conclusive statements about a possible correlation of high toxicity bio magnification throughout the food chain.

Alternative outcomes would include little or no impact on the multiple organ systems in marine water organisms. We could also observe little to no microplastic accumulation observed overtime in the water bodies. Moreover, based on these alternative results, we would have no direct correlation and/or causation between microplastics and poor aquatic health and no grounds for correlation between marine microplastic toxicity and poor human health.

Results and Discussion:

Ingestion of Microplastics and their encounter pathways:

Table 1 shows ingestion pathways for microplastics in select marine organisms. It is observed that the likelihood of minute plastics particles being ingested depend on factors such as electric charge, size, density, sediment and location (surface or sinking). While these may vary between species, a general trend indicates that ingestion of microplastics is facilitated by multiple factors; making it all that easier to invade marine organisms.

Table 1: 'Marine organisms susceptible to microplastic ingestion and their encounter pathways' (Wright et al., 2013).

Taxa	**Encounter pathway**
Marine algae e.g. *Scenedesmus*	Adsorbs nanoplastics, especially when positively charged.

Grazing microzooplankton e.g. the marine ciliate *Strombidium sulcatum*	Size-based selectivity indicates potential to ingest microplastics of appropriate size.
Benthic deposit feeders e.g. the polychaete *Arenicola marina* and the holothurian *Holothuria floridana*	The sea bed is a sink for high-density microplastics; size-based, deposit- feeding strategies adopted by *A. marina* indicate potential to ingest microplastics of appropriate size; *H. Floridana* selectively ingests plastic particles, showing a preference for fibrous shapes.
Benthic scavengers e.g. the crustacean *Nephrops norvegicus*	Fibrous microplastics have been found to accumulate in marine sediments; gut content analysis has shown plastic microfibers are being ingested in the environment; ingestion is passive via food it scavenges or sediment.
Mesozooplankton e.g. echinoderm larvae, calanoid copepods, chaetognaths	Low density microplastics present on the sea surface with greatest abundances in gyres and industrial harbors; size-based selectivity indicates potential to ingest microplastics of appropriate size.
Benthic suspension feeders e.g. the bivalve *Mytilus edulis*	Susceptible to sinking microplastics; have been found to ingest microplastics despite low qualitative value.

Accumulation and Translocation:

The risk of microplastic ingestion on the physical health of marine organisms significantly increases with increased accumulation of microplastic particles within the organisms' vital body systems (Wright et al., 2013). Through laboratory research, it was found that microplastics accumulate at a high concentration within the digestive cavity and tubules of bivalve mollusks (Brillant and MacDonald, 2000; Browne et al., 2008). Furthermore, it was also observed that up to 20 μm of microplastics had accumulated in the primary ducts and tubules within the digestive gland of a sea scallop. After accumulation, the microplastics remained within the digestive gland for 48 hours (Brillant and MacDonald, 2000). Scientists within the field observed accumulations of microplastics within the vital structures of a marine organism's body could create possible blockages. These blockages could then hinder functions required for

the organism's survival. One such example is that blockage within the digestive system of a marine organism due to microplastic accumulation would inhibit feeding by creating a feeling of satiation. As a result, the organism would be unable to feed at a rate required for its survival (Wright et al., 2013).

Moreover, microplastics do not just create dire problems by accumulating within organisms. They also hinder vital functioning by external adsorption. A study by Bhattacharya et al. (2010) found that plastic beads the size of 20 nm attached themselves to the surface of *Chlorella* and *Scenedesmus* and obstructed photosynthesis. *Chlorella* belongs to the order Chlorellales and family Oocystaceae while *Scenedesmus* belongs to the order Sphaeropleales and family Scenedesmaceae. While they belong to different families and orders, both these organisms reside under the same kingdom Plantae and division Chlorophyta (NODC Taxonomic Code, 1996). It was concluded that the potential cause of this reduced photosynthetic activity in algae was due to the blockage of sunlight and air by the plastic beads. These plastics beads on algae were also found to create 'oxidative stress' by increasing production of reactive oxygen species (Bhattacharya et al. 2010).

While studying the literature on translocation, it was observed that filter feeding marine species lack enzymatic pathways that would allow the breakdown of microplastics. As a result, it is difficult for microplastics to be digested or absorbed in the case of filter feeders. This is relevant due to the fact the microplastic particles then choose an alternative pathway by moving through the organism's cell membranes. After ingestion, via the cell membranes, microplastic particles are then able to incorporate themselves in the tissue of the organism's body (Andrady, 2011).

Furthermore, laboratory experiments conducted on translocation of microplastics have shown that suspension feeders, specifically *Mytilus edulis* (Blue Mussel), have shown quick and intensive translocation into its circulatory system via the epithelial lining of the gut. After translocation to the circulatory system it was found that microplastics have the ability to remain within the organisms' internal system for multiple weeks. In *M. edulis*, the microplastic particles were retained in the hemocyte and hemolymph for up to 48 days. Unfortunately, the exact mechanism and translocation time through the gut lining has not been determined (Browne et al., 2008). From the results of this study, generalizations can be created stating this trend of retention after translocation could occur in all marine organisms. Consequently, it is possible that this high rate of retention and accumulation would cause increased physical harm as well as increased chances of microplastic movement through the trophic system (Wright et al., 2013).

In another scientific experiment that studied the significance of particle size on translocation, it was observed that smaller particle with a size of 3 μm showed over 60% of translocation in the hemolymph and hemocytes of the model organism. This trend was then observed again in the enterocytes of rats. Particles the size of 14 nm translocated to the rat enterocytes within 2 mins of exposure. Whereas, particles the size of 415 nm took 30 mins to translocate (Hussain et al., 2001). These data help us draw the conclusion that a smaller particle size of plastics causes an increased rate of translocation. It is also important to note that enterocytes are the primary route of transportation for particles in humans. Particles translocate via phagocytosis from the epithelial cells into the circulatory systems of humans (Wright et al., 2013). Therefore, it can be approximated that ingestion of microplastics in humans would lead to translocation within the body via the enterocytes.

Movement within trophic levels:

There are few studies on the bioaccumulation of plastics and microplastics within marine trophic levels. However, due to the fact the organisms at the lower end of the trophic chain, specifically invertebrates ingest and accumulate microplastics, an assumption can be derived, expressing that these microplastic particles will inevitably enter our food web (Wright et al., 2013).

Although there is a lack of abundant scientific data at present to support the theory of definitive bio magnification of microplastics, there are studies that show trophic transfer of plastic by-products such as dioxins, polychlorinated biphenyl (PCBs) and polybrominated diphenyl ethers (PBDEs). These compounds are often found in plastic litter that contaminate oceans and other water bodies (Ogata et al., 2009). Although bio magnification through trophic levels depends on multiple factors such as 'octanol-water partition coefficient' and 'metabolic transformation rates' (Wan et al., 2005), toxic plastic byproducts including PCBs and dioxins have been known to bio magnify (Hu et al., 2005). It is hence plausible to suggest that microplastics can move from lower trophic levels to higher trophic levels and bio magnify.

Furthermore, in a study conducted on *Arctocephalinae* (fur seals) and *Phocarctos hookeri* (Hooker's sea lions), it was observed that microplastic particles with an approximate diameter of 1mm were found in the droppings of both these organisms. It was suggested that organisms on the higher end of the trophic system could possibly absorb microplastics from their prey via feeding (Goldsworthy et al., 1997; McMahon et al., 1999).

Physiological Effects:

Microplastics such as BPA, polystyrene, etc. have shown large numbers of negative impacts on marine health. Based on the review of existing scientific literature, some significant physiological effects on marine health have been compiled and discussed. One of the leading

health problems associated with BPA is disruption of the endocrine systems of marine organisms (Bosnjak, 2013).

In an experiment conducted on *Echinoidea* commonly known as sea urchins, effect of BPA on embryos of sea urchins has been found to have cytotoxic effects, causing impairment and retardation in embryo development during the first phase of cell division. This occurred because BPA caused a delay in mitosis, abnormal karyokinesis and damaged microfilaments (Bosnjak, 2013).

Disruptions in the endocrine system and cell division then significantly impact reproductive health. For example. in the same study, BPA was used for an embryotoxicity assay at various concentration with 10 μM being the highest level of BPA used. It was found that fifty percent of embryos of sea urchins were unable to complete the first phase of cell division at a concentration of 1.7μM of BPA (Bosnjak, 2013). Furthermore, spermiotoxic and embryotoxic effects were observed in sea urchins due to the influx of BPA (Bosnjak, 2013).

Another example of poor reproductive health due to microplastics was found in *Daphnia magna*, commonly known as Daphnia. Exposure of nano-polystyrene caused a reduction in body size of neonates and significant changes in the reproduction of *Daphnia magna*. Neonate malformations increased in up to 68% of the individuals at a minimum concentration of 30 mg of nano-PS/L (Besseling et al., 2014).

With an increase in the concentration of plastic litter over time, and subsequent formation of microplastics in the marine ecosystem, endocrine and reproductive health of organisms within this ecosystem can undergo detrimental population loss, increased mortality rate and poor fitness due to poor neonatal formation and cell division. Although significant negative impacts on reproductive health of marine organisms due to microplastics may not be classified as an urgent

matter in present times, it is crucial to utilize existing literature as a foundation for the formation of an advanced long-term picture. With excessive use of plastic products, increasing demand, ineffective substitutes and lack of knowledge about the consequences of microplastics within our society, it is very likely that accumulation of microplastics in the marine environment could cause a significant decline in the health and survival of organisms within the ecosystem.

Moreover, microplastics were also found to have a negative physiological effect on the digestive system, gene expression, enzyme activity and cell activity in organisms exposed to microplastics. For example, In *M. Edulis*, after ingestion and accumulation of microplastics in the digestive gland it was observed that the blue mussels showed signs of granulocytoma formation, increased hemocytes as well as a substantial reduction in stability of lysosomes (GESAMP, 2010). Another study found that microplastics, specifically BPA, can potentially alter gene expression, enzyme activity essential for the redox balance and lysosomal function necessary for metabolic control and maturation of gametes in the hepatopancrease of mollusks (Canesi et al., 2007).

Microplastics accumulating and attacking marine organisms at a cellular level and interfering with critical functions such as gene expression can have detrimental effects on the life-span and quality of life of both neonates and adults. Poor gene expressions and possible increase in subsequent mutations could drastically decrease fitness, causing natural selection to eliminate substantial populations of various marine species. Lack of enzymatic activity and cellular metabolism would hinder normal functioning of vital organ systems, allowing marine organisms to fail at maintaining functions required for survival. Similar to the potential long-term impacts of poor reproductive and endocrine health, overtime, with increased accumulation of microplastics in the marine ecosystem, organisms could face a severe population decline.

In organisms such as green algae, a laboratory experiment showed that exposure to minute plastic particle, specifically nano-polystyrene caused a reduction in chlorophyll concentration and the population growth rate in green algae (Besseling et al., 2014). Chlorophyll being a photoreceptor in algae, is necessary for the process of photosynthesis [May, (n.d.)]. Algae are a vital part of the marine ecosystem and play an important role by offering oxygen as well as a potential food source to the marine organisms (NOAA, 2014). Due to their tremendous and broad populaces, algae along with cyanobacteria contribute towards almost fifty percent of the oxygen found in the sea and atmosphere (WHOI, 2014). With a reduction in chlorophyll levels due to minute plastic particles, there is a potential threat of poor oxygen levels and low food resources within the marine ecosystem due to reduced photosynthesis.

On a broader scale, the long-term consequences of increasingly low oxygen levels in the marine ecosystem can have human health impacts. Not only will the health of marine organisms decline due to poor oxygen content; lack of photosynthesis and subsequent low oxygen levels would be extremely dangerous, if not fatal for human life.

While it can be easy to state that this is a far-fetched theory, studying the long-term effects of microplastic and other minute plastic particles over extended periods of time would allow society to observe and understand the merit and significance of this correlation.

Although the physiological effects discussed so far on the health of marine organisms are significantly negative, there is yet another undesirable impact of microplastic that has been observed through recent research. In order to combat the negative effects of microplastics on the organism's physical system, energy is expended to support the overload caused on the immune system. As a result, regular physiological systems are deprived of energy expenditure causing a decline in performance. This can have significant long-term impacts on the health of the organism

(Wright et al., 2013). Most marine organisms require energy expenditure and metabolic activity for crucial functions such as breathing, adapting to temperature etc. (N.A., 2009). Furthermore, high metabolic demand is required for functions such as locomotion which is crucial for both predators, as well as prey for survival. Natural selection exhibits a preference for high locomotive ability and increased energy expenditure for locomotion (Seibel et al., 2007).

If marine organisms require energy for functions necessary for survival, they would have to pay a hefty cost due to the accumulation of microplastics and deviation of energy expenditure caused by the negative physiological effects of the microplastics. In cases with extreme physiological damage, the organism may have to expend almost all of its energy on trying to repair the damage and reduce accumulation of microplastics within the body. This would most likely cause a drastic decline in functions such as locomotion and feeding. Over time, lack of crucial functions could become the cause of mortality in organisms with high energy expenditure due to microplastics. Even though microplastics would not be considered the direct cause of mortality, these minute plastic particles would be responsible for the slow decline in physiological functioning thereby becoming the indirect reason for the demise of the organism.

The aim of this literature review study was to better understand the impact of microplastics on the health of marine organisms. From this study, it can be concluded that microplastics have significant negative health impacts on the vital systems of marine organisms including endocrine, circulatory, reproductive, cellular and digestive systems. There appears to be a direct as well as indirect effect of microplastics on the health of marine organisms. However, while it is natural to draw a clear conclusion which supports the expected outcomes of this study, it is also important to acknowledge that in order to reach a toxic level of microplastic accumulation in the marine ecosystem, a significant amount of time has to lapse to create a potential ecological crisis.

Nevertheless, that does not eliminate the possibility of such an event occurring soon in our biological timeline. In order to maintain balance in the marine ecosystem, prevent endangerment and extinction of marine species and reduce the risk of the food web collapsing, it is vital to not just prevent microplastic accumulation in the marine environment, but also further study the long-term effects of microplastics in great detail.

Another probable reason to better understand microplastic accumulation is the possibility of similar negative impacts on human health via ingestion through movement within trophic levels and bio magnification.

Although there is a lack of scientific data supporting the phenomenon of definite movement of microplastics through trophic levels and subsequent toxicity by bio magnification, based on the current data, it is plausible to draw positive correlation between microplastic ingestion at lower trophic levels and toxicity at higher trophic levels. Even though there has been limited research on this topic, the conceivable risk of microplastic toxicity at higher trophic levels beyond the marine realm makes the limited literature extremely valuable. Transfer of microplastics from one trophic level to the next would cause a toxic loop of chemical transfer making it almost impossible to eliminate. Being unable to contain contamination between multiple ecosystems would cause significant damage to populations of a variety of species.

At present time, microplastic accumulation is mostly contained within the marine ecosystem. In order to ensure positive physiological health and absence of microplastics at higher trophic levels, containment of microplastic contamination and reduction of microplastic accumulation is very important.

Another chief aspect of this study was the focus on highlighting the significance of accumulation and translocation in the process of microplastic contamination. It was observed that

accumulation and translocation are the fundamental routes that permit side effects of microplastic to occur. Although these processes occur internally within the organism's body and are nearly impossible to control or eliminate, it is possible to reduce the degree of accumulation and translocation and their subsequent negative impacts on marine health by reducing plastic waster in marine ecosystems.

Even though accumulation and translocation pave the way for microplastics to wreak havoc on marine health, it is possible to consider these processes as an indicator for a possible solution of microplastic toxicity. By making reduction of the amount of plastic waste and litter generated by society as the primary focus, it is possible to reduce the probability of ingestion and subsequent accumulation significantly. This would then eliminate risks on the health of marine organisms and possible bio magnification.

Accumulation and translocation are not the only factors that impact microplastic toxicity. As observed in the literature review, factors including size, density and shape of microplastics impact their movement within marine ecosystems. Although we have scientific data which highlights the importance of these factors, there is not enough information to draw definite conclusions on the significance of these properties on the movement of microplastics through marine ecosystems and various mechanisms that are impacted by these properties. However, the involvement and impact of these versatile factors create a multi-layered barrier between eliminating microplastic toxicity and poor marine health. In order to prevent marine organisms from experiencing physiological health deficits from microplastic accumulation, it is vital to construct strong solutions to eliminate microplastics in the marine environment.

However, the presence of multiple factors impacting rate of absorption can reduce the effectiveness of a single solution, creating a demand for multiple solutions to tackle the various

versatile factors. Not only does this cause a radical increase in time and money invested in research, it would also increase the time span of preventative and curative measure required to reduce microplastic toxicity.

Although it may appear as though the scientific community has an advantage of extended time due to the extremely slow degradation of large plastic litter, the presence of multiple factors including shape, density, size, translocation and accumulation make this large window of time nearly inadequate.

Due to this battle against time, high demand of plastic, increasing population growth and lack of awareness, future research in this field is crucial. Some of the future areas of research in this field include understanding the ultimate destination of microplastics in marine invertebrates and conducting extensive laboratory research studies to learn the potential harmful effects of microplastics on aquatic health. Physical impacts of micro and nano plastics still remain unclear despite their large threat to aquatic health (Wright, 2012).

Other possible areas of research that need to be studied in this field include the role of microplastics as vectors for persistent organic pollutants, the movement of microplastics within the tropic levels and higher up on the food chain and the effects of plastic particle shape, size and density on toxicity within the marine environment (Wright, 2012). These issues need to be examined since in their own way, each problem contributes to the long-term deterioration of marine and human health. The distribution and movement of microplastics can depend significantly on the particle size and density, while the introduction of these harmful particles within any food chain can cause poor health due to ingestion. Also, better understanding these questions can help prevent loss and damage of marine and human life.

However, in cases where health degradation has already begun, research both experimental and literature reviews will help create effective strategies and design plans to potentially cure or improve the health of organisms, as well as prevent future reoccurrence.

Overall, from this literature review it can be concluded that microplastic accumulation due to an alarmingly high rate of plastic litter in marine ecosystems is increasing. Microplastics have been found to enter marine organisms via various methods of absorption including vectors, feeding etc. The rate of absorption depends on factors such as shape, size and density of the microplastic particles. Once absorbed, these microplastic particles translocate within the body and accumulate in various regions of the organism's vital systems. Accumulation allows the microplastics to reside within the organisms long enough to negatively impact marine health.

Some vital functions negatively impacted by microplastics are endocrine, reproductive, cellular, circulatory and digestive. Examples in the scientific literature exhibit poor gene expression, neonatal deformities, swelling in cell structures, reduced chlorophyll production etc. Almost all of the health impacts observed in the literature have detrimental and even fatal long-term effects. This threatens the stability of the marine ecosystem by endangering large species populations.

Lastly, a great amount of research is further required in this field to better understand aspects of microplastic toxicity such as effects on the food web, bio magnification through trophic levels, significance of microplastics as vectors and the importance of factors such as size, shape and density on the movement of microplastics within the organism's body. It is also important to utilize existing and future research in the field to create potential solutions to reduce the probability of increased microplastic contamination in marine ecosystems.

References

Andrady, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin*, 62(8), 1596-1605. doi:10.1016/j.marpolbul.2011.05.030

Ashraf, Abdullah. (2014). FTIR & UV-Vis analysis of Polymer(Polystyrene, LDPE) samples. . 10.13140/2.1.3819.0880.

Besseling, E., Wang, B., Lürling, M., & Koelmans, A. A. (2014). Nanoplastic Affects Growth of S. obliquus and Reproduction of D. magna. *Environmental Science & Technology,48*(20), 12336-12343. doi:10.1021/es503001d

Boerger, C. M., Lattin, G. L., Moore, C. J., & Moore, S. L. (2010). Plastic ingestion by planktivorous fishes in the north pacific central gyre. *Marine Pollution Bulletin*, 60(12), 2275-2278. doi:10.1016/j.marpolbul.2010.08.007

Bosnjak, I., Borra, M., Iamunno, F., Benvenuto, G., Ujevic, I., Buselic, I., . . . Mladineo, I. (2014). Effect of bisphenol A on P-glycoprotein-mediated efflux and ultrastructure of the sea urchin embryo. *Aquatic Toxicology*, 156, 21-29. doi:10.1016/j.aquatox.2014.07.018

Brillant, M., & MacDonald, B. A. (2000). Postingestive selection in the sea scallop, placopecten magellanicus (gmelin): The role of particle size and density. Journal of *Experimental Marine Biology and Ecology*, 253(2), 211-227. doi:10.1016/S0022-0981(00)00258-6

Browne, M.A., Galloway, T.S., Thompson, R.C., 2007. Microplastic an emerging contaminant of potential concern? *Integrated Environmental Assessment and Management* 3 (4), 559e561.

Browne, M.A., Dissanayake, A., Galloway, T.S., Lowe, D.M., Thompson, R.C., 2008. Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L.). *Environmental Science and Technology* 42 (13), 5026e5031.

Browne, M.A., Crump, P., Nivens, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R., 2011. Accumulation of microplastics on shorelines worldwide: sources and sinks. *Environmental Science and Technology* 45 (21), 9175e9179.

Bhattacharya, P., Lin, S., Turner, J.P., Ke, P.C., 2010. Physical adsorption of charged plastic nanoparticles affects algal photosynthesis. *The Journal of Physical Chemistry* C 114, 16556e16561.

Canesi, L., Borghi, C., Ciacci, C., Fabbri, R., Vergani, L. and Gallo, G. (2007). Bisphenol-A alters gene expression and functional parameters in molluscan hepatopancreas. *Molecular and Cellular Endocrinology*, 276(1-2), pp.36-44.

Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the marine environment: A review. *Marine Pollution Bulletin*, 62(12), 2588-2597. doi://doi.org/10.1016/j.marpolbul.2011.09.025

Corcoran, P. L. (2015). Benthic plastic debris in marine and fresh water environments. *Environmental Science-Processes & Impacts*, 17(8), 1363-1369. doi:10.1039/c5em00188a

Close, B., Banister, K., Baumans, V., Bernoth, E., Bromage, N., Bunyan, J., . . . Warwick, C. (1996). *Recommendations for euthanasia of experimental animals: Part 2* (Vol. 358, Tech.). DGXI of the European Commission. Retrieved from http://journals.sagepub.com/doi/pdf/10.1258/002367797780600297

Dakhale, G. N., Hiware, S. K., Shinde, A. T., & Mahatme, M. S. (2012). Basic biostatistics for post-graduate students. *Indian Journal of Pharmacology*, *44*(4), 435–442. http://doi.org/10.4103/0253-7613.99297

Du, C. C., Mashoof, S. M., & Criscitiello, M. F. (2012). Oral immunization of the African clawed frog (*Xenopus laevis*) upregulates the mucosal immunoglobulin IgX. *Veterinary*

Immunology and Immunopathology, *145*(1-2), 493–498. http://doi.org/10.1016/j.vetimm.2011.10.019

Eerkes-Medrano, D., Thompson, R. C., & Aldridge, D. C. (2015). Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. *Water Research*, 75, 63-82. doi:10.1016/j.watres.2015.02.012

Fotopoulou, K. N., & Karapanagioti, H. K. (2015). Surface properties of beached plastics. *Environmental Science and Pollution Research*, 22(14), 11022-11032. doi:10.1007/s11356-015-4332-y

Faupel-Badger, J. M., Fuhrman, B. J., Xu, X., Falk, R. T., Keefer, L. K., Veenstra, T. D., . . . Ziegler, R. G. (2010). Comparison of Liquid Chromatography-Tandem Mass Spectrometry, RIA, and ELISA Methods for Measurement of Urinary Estrogens. *Cancer Epidemiology Biomarkers & Prevention,19*(1), 292-300. doi:10.1158/1055-9965.epi-09-0643

GESAMP (2010, IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Bowmer, T., Kershaw, P.J., (Eds.), 2010. Proceedings of the GESAMP International Work- shop on Plastic Particles as a Vector in Transporting Persistent, Bio- accumulating and Toxic Substances in the Oceans. GESAMP Rep. Stud. No. 82, 68 pp

Hardy, J. D. (1997). *NODC taxonomic code*. Silver Spring, MD: U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, National Oceanographic Data Center.

Im, J., & Loffler, F. E. (2016). Fate of bisphenol A in terrestrial and aquatic environments. *Environmental Science & Technology*, 50(16), 8403-8416. doi:10.1021/acs.est.6b00877

J Sherry, A Gamble, M Fielden, P Hodson, B Burnison, & K Solomon. (1999). An ELISA for brown trout (Salmo trutta) vitellogenin and its use in bioassays for environmental estrogens. *Science of The Total Environment*. doi:http://www.sciencedirect.com/science/article/pii/S004896979980014X

Lambert, S., & Wagner, M. (2016). Exploring the effects of microplastics in freshwater environments. *Integrated Environmental Assessment and Management*, 12(2), 404-405. doi:10.1002/ieam.1754

May, P. (n.d.). Chlorophyll. *In School of Chemistry*. Retrieved from http://www.chm.bris.ac.uk/motm/chlorophyll/chlorophyll_h.htm

Müller, C., Townsend, K., & Matschullat, J. (2012). Experimental degradation of polymer shopping bags (standard and degradable plastic, and biodegradable) in the gastrointestinal fluids of sea turtles. *Science of the Total Environment*, 416, 464-467. doi:10.1016/j.scitotenv.2011.10.069

NA, (2016). What are micro plastics? National Ocean Service: *National Oceanic and Atmospheric Administration*; Retrieved from http://oceanservice.noaa.gov/facts/microplastics.html

NOAA. (2014, April). What are Phytoplankton?. *In National Ocean Service*. Retrieved from http://oceanservice.noaa.gov/facts/phyto.html

Nash, J., Davail-Cuisset, B., Bhattacharyya, S., Suter, H. C., LeMenn, F., & Kime, D. E. (2000). An enzyme linked immunosorbant assay (ELISA) for testosterone, estradiol, and 17,20 - dihydroxy-4-pregenen-3-one using acetylcholinesterase as tracer: application to measurement of diel patterns in rainbow trout (Oncorhynchus mykiss). *Fish Physiology and Biochemistry*,*22*(355), 363rd ser. doi:https://link.springer.com/content/pdf/10.1023%2FA%3A1007850014021.pdf

Seltman, H. J. (2012). *Experimental Design andAnalysis* (Vol. 428). Pittsburgh: Carnegie Mellon University.

Seibel, B. A., & Drazen, J. C. (2007). The rate of metabolism in marine animals: Environmental constraints, ecological demands and energetic opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences,362*(1487), 2061-2078. doi:10.1098/rstb.2007.2101

Torreilles, S. L., McClure, D. E., & Green, S. L. (2009). Evaluation and Refinement of Euthanasia Methods for *Xenopus laevis*. *Journal of the American Association for Laboratory Animal Science : JAALAS*, *48*(5), 512–516.

Wagner, M., Scherer, C., Alvarez-Muñoz, D., Brennholt, N., Bourrain, X., Buchinger, S., . . . Reifferscheid, G. (2014). Microplastics in freshwater ecosystems: What we know and what we need to know. *Environmental Sciences Europe*, 26(1), 1-9. doi:10.1186/s12302-014-0012-7

Walsh, PT, Downie, JR & Monaghan, P 2008, 'Plasticity of the duration of metamorphosis in the African clawed toad' *Journal of Zoology*, vol 274, no. 2, pp. 143-149. DOI: 10.1111/j.1469-7998.2007.00367.x

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013a). The physical impacts of microplastics on marine organisms: A review. *Environmental Pollution*, 178, 483-492. doi:10.1016/j.envpol.2013.02.031

Weissgerber, T. L., Garovic, V. D., Milin-Lazovic, J. S., Winham, S. J., Obradovic, Z., Trzeciakowski, J. P., & Milic, N. M. (2016). Reinventing Biostatistics Education for Basic Scientists. *PLoS Biology*, *14*(4), e1002430. http://doi.org/10.1371/journal.pbio.1002430

WHOI. (2014). Phytoplankton. *In Ocean Life*. Retrieved from http://www.whoi.edu/main/topic/phytoplankton

Zbyszewski, M., & Corcoran, P. L. (2011). Distribution and degradation of fresh water plastic particles along the beaches of lake huron, canada. *Water, Air, & Soil Pollution*, 220(1), 365-372. doi:10.1007/s11270-011-0760-6

Table 1:

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013a). The physical impacts of microplastics on marine organisms: A review. Environmental Pollution, 178, 483-492. doi:10.1016/j.envpol.2013.02.031