THESIS

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Microplastic in the food chain – Food Safety and Environmental aspects

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Acronyms and Abbreviations

ALDFG – Abandoned Lost Discarded Fishing Gear

BPA – Bis Phenol A

EFSA – European Food Safety Authority

G7/G20 - Group of 7/20

HBDC - Hexabromocyclododecane

HDPE – High Density Polyethylene

ICI – Imperial Chemistry Industry

ISO – Industrial Organisation for Standardisation

LLDPE – Light Low Density Polyethylene

LDPE – Low Density Polyethylene

MT – Million tonnes

NP – Nonylphenols

PA – Polyacrylamide

PAH – Polycyclic Aromatic Hydrocarbons

PBDE – Polybrominated diphenylethers

PBP- Penicillin Binding Proteins

PE – Polyethylene

PMMA – Polymethylmacrylate

POPs – Persistent Organic Pollutants

PP – Polypropylene

PS - Polystyrene

PVC - Polyvinylchloride

SUP – Single Use plastic

UN – United Nations

UV - Ultraviolet

1. INTRODUCTION

Plastic is intrinsic to modern life. Since the invention of Bakelite in 1930 plastic has lived up to its reputation as the "Material of a thousand uses" (Gilbert, 2017). Human beings use plastic in many different ways every single day, and it has propelled invention and advances in many industries including medicine, construction and engineering. The problem with plastic began with the development of a "throwaway culture" made feasible by the invention of "single use plastics", most frequently used in packaging of various products. This coupled with countries having underdeveloped waste disposal methods to cope with the large volumes of plastic in use and production has led to a large buildup of plastic materials, notably packaging, heading straight for landfill, incineration or the environment in the form of litter (Hayden et al., 2013; Shah et al., 2018). Plastic is favoured for its outstanding durability, but it is this trait which has led to problems associated with its degradation, especially when it reaches environment.

It has been estimated that the amount of plastic entering the ocean yearly is 8 million tons (Jambeck et al., 2015) and that plastic pieces floating around in the oceans water column could exceed 5 trillion (Eriksen et al., 2014). Plastic is accumulating in ecosystems at ever increasing rates. These plastic pieces have been found all around the world from deep ocean gyres to surface waters as well as in every terrestrial and freshwater habitat (Carbery et al., 2018; Rilig, 2012).

Plastics are made most often from a petrochemical waste product of the fossil fuel industry, they are materials of high molecular mass usually derived from ethylene, propylene and styrene. They emit many greenhouse gases both in their manufacture and in their degradation, such as ethylene, carbon dioxide and methane (Hayden et al., 2013; Soares, 2008 and Hirai, 2011). Various chemical additives can be added to the plastic during its manufacture depending on its potential use. The top 2 additives used in plastic manufacture that were found in environmental plastic debris were; 1. Phthalates such as Bis Phenol A and 2. Flame retardants such as Nonylphenols (NP), Polybrominated diphenyl ethers (PDBEs) and hexabromocyclododecane (HBDC). The reason phthalates are added to plastic is because they increase the flexibility and durability (Oehlmann et al., 2009). The flame retardants feature in plastics as safety devices where the desire is to reduce the flammable quality of a product. These additives have been documented to escape the polymers in which they were combined with throughout the life of the plastic as it is being used, manufactured or when it is disposed (Talsness et al., 2009). When plastic litter makes its way into our environment it means that these additives become bioavailable to the organisms which reside there (Cheng et al., 2013). This is also how they become incorporated into various food webs such as the marine, aquatic or terrestrial. Nonylphenols are mostly found in the effluent from wastewater treatment plants and has been found associated with many microplastics found as plastic debris (Mackintosh et al., 2004). These chemical additives have been linked to various health risks including endocrine disrupting activities, liver and kidney toxicity and teratogenicity. They can also leach into the environment in a similar way and are known as persistent organic pollutants (POPs). HBCD is used often in polystyrene products and have also been found in buoys used in fisheries and in marine debris, and again have been allegedly linked to endocrine disruption and are also POPs (Yogui et al., 2009; Al-Odaini et al., 2015).

It is for this reason that it is important to produce, recycle, reuse and dispose of plastics in a way that isn't wasteful or harmful to the environment in order to prevent unnecessary expenditure of gases and chemical additives. In Germany there are waste processes in place that work very well whereas Ireland rely on shipping up to 95% of their plastic waste to other countries to be recycled, incinerated or buried in landfill (Patel, 2000; O'Sullivan, 2017).

Until 2017 China took many other country's plastic and paper waste but in December of that year they declared they would no longer be the world dumping ground and so countries have been faced with their own waste to deal with (O'Sullivan, 2017). In Europe the declaration for a ban on single use plastic and the creation of a circular economy in 2019 were great steps forward in the road to tackling plastic waste production and disposal issues (European Commission, COM/2019/190).

Plastic waste comes in many sizes such as macro-, meso-, microplastic, microfibres and nanoplastics. All sizes and types of plastic and their associated chemicals are making their way into the environment through legal and illegal dumping, littering and landfill. Macro- and meso- plastic cause obvious devastation to wildlife and nature through such processes as entanglement, as well as being an eye sore when found discarded or washed up in nature (Carbery et al., 2018; Lusher et al., 2017; Hayden et al., 2013).

Microplastics are divided into primary, secondary and tertiary;

- Primary microplastics are often added to cosmetic products as exfoliant and then wash down the drain and into the freshwater rivers, lakes and the sea.
- Secondary Microplastics are the result of larger meso- or macroplastics which have been broken down or degraded to smaller fragments by weathering through UV light and exposure to other physical or biological processes (Batel et al., 2016).
- Tertiary microplastics are plastic pellets which are the building blocks of plastic material.

These tiny plastics, if they make their way into ecosystems are then often mistaken as a food source for a selection of invertebrates within marine, freshwater and terrestrial ecosystems as well as juvenile fish species and are entering the food chain or causing damage to these creatures after direct and indirect ingestion (Rilig, 2012).

Although chemically inert, plastic has shown to have the property of a "biosponge" meaning that it is very conducive to the adherence of various chemicals both added to the plastic during production or taken up from the environment in which it has found itself in such as a polluted part of the ocean, freshwater rivers, lakes or the soil (Rochman et al., 2013b). This quality makes plastic potentially toxic if ingested due to the nature of the chemicals which have been found adsorbed to the surface of microplastics (Raza et al., 2018, Batel et al., 2016).

Microplastics have been aptly described as being ubiquitous in the environment; meaning that they have been found everywhere. This fact raises concerns regarding potential microplastic incorporation into the human food chain and it has been proven through various studies that humans are ingesting plastic from an array of sources (Van Cauwenberghe and Janssen, 2015). It is important to determine the main routes of ingestion and how they can be quantified and prevented, and to conduct toxicological studies to determine the concentrations in which they cause harm or are toxic to human consumers. Many studies have been done with these questions in mind. Most have been conducted under laboratory conditions and exposures have often been much higher than would be found naturally in the environment, however, they still provide an indication as to the problems microplastics may cause if they continue to build up in the environment or within organisms.

Unfortunately, methods for quantifying plastic in the environment are only beginning to be developed and so it is difficult to grasp the scale of the problem, that is why it is necessary to develop new methods for detecting plastic within food items and study bioindicator species to help us monitor the plastic in the ecosystem and its effects. We must look at the trophic cascade to determine potential hazards that could be inflicted upon humans and the animals within the complex food webs of various ecosystems (Carbery et al., 2018; Batel et al., 2016)

The problem with plastic is that it is not the only potential risk issue facing our environment; climate change, over population, political unrest, habitat fragmentation and loss, forest fires, loss of biodiversity, collapse of fish stocks due to overfishing, invasive species, acidification of the oceans, and pollutants from other sources such as heavy metals are also playing their part in threatening global biodiversity and species worldwide, but plastic too plays a role in contributing to the pressures faced in the natural world. The plastic problem is just additive to these pressing concerns and it is important to grasp the impact it may be having in terms of food safety for human and animal consumers and in protecting the biodiversity of our wildlife habitats. It must be noted that whatever is damaging to the environment will be damaging to humans in some way.

"In isolation, microplastics might not be the single most toxic (lethal or sublethal) environmental contaminant. However, there are consistent past, present, and future trends of increasing a near-permanent plastic contamination of natural environments at a global scale" (Geyer et al., 2017).

This literature review is based on the trends in plastic production and human interaction with plastic, the routes in which plastic may enter the food chain and the potential toxic or harmful effects they may pose to invertebrate and vertebrate organisms as well as careful attention paid to the food safety and security regarding humans as the main consumer of interest. Using where possible the most recent literature dedicated to researching these issues.

2. LITERATURE REVIEW

2.1 Plastic Material

The word plastic was derived from the Greek word "Plastikos" which means "capable of being shaped or moulded". This aptly describes the ductile and malleable nature of the material we know as plastic. It is a material consisting of a wide range of synthetic or semi synthetic organic compounds which can be moulded into solid objects (Lusher et al., 2017).

"Plastic" is an umbrella term referring to a very large family consisting of many different materials all with varying characteristics, properties and uses. Plastic can be utilized in many areas of life and so explains the ubiquitous nature of the product. Plastic polymers have innumerable applications from microplastics, food packaging, clothing, toys, medical implants, piping, plumbing, furniture etc (Lusher et al., 2017). The invention of plastic initially meant less reliance on natural materials such as wood, bone, tortoiseshell, horn, metal, glass and ceramics, which was a benefit to the environment, however, due to humans ever increasing reliance on plastic and its ability to find its way into the environment, plastic has proven quite the burden on the natural world, accumulating in terrestrial, marine and aquatic ecosystems (Andrady, 2011; Machado et al., 2018).

Usually plastic is derived from either fossil fuel based or bio based materials, both of which can be degradable if disposed of correctly, however most often plastic disposal follows three main routes; landfill, incineration, recycling or littering (Machado et al., 2018; Hayden et al., 2013; Shah et al., 2011). From the aspect of environmental pollution plastic has become a focus due to the fact that much of it finds its way into the environments through many routes. It was estimated that every year 8 million tonnes of plastic waste enters the ocean, this plastic then further interacts with almost 700 marine species (Andrady, 2011; Gall and Thompson, 2015).

Plastic can be divided up into a range of sizes, macroplastics, mesoplastics, microplastics and nanoplastics. Microplastics are regarded as plastics less than 5 mm in size or between 5 – 1000 micrometres (Van Cauwenberghe and Janssen, 2014; Smith et al., 2018). Nanoplastics are regarded as 0.001 micrometres (Lambert and Wagner, 2016). Macro and mesoplastics typically make up the plastic litter that is visible to the naked eye with microplastics and nanoplastic consisting of plastic we usually cannot see easily or at all (Smith et al., 2018). Macroplastics can cause problems such as entanglements, ingestion in larger animals, are an eyesore in the environment etc. but micro- and nanoplastics can cause problems such as bioaccumulation and biomagnification within the food chain if ingested, these plastics also pose a threat due to their potentially toxic effects when acting as a biosponge (Lusher et al., 2017).

It has been documented and will be discussed later how microplastics are interact with or are ingested by many small invertebrates such as Daphnii, Mussels and Earthworm across a range of ecosystems with organisms being affected either at the tissue or cellular level (Lwanga et al., 2017; Setälä et al., 2014; Farrel and Nelson, 2013).

Sometimes plastic can have additives incorporated into their creation process in order for them to have a variety of uses. These additives have the potential to be harmful to the environment and cause also harm to body tissues in large quantities (Andrady, 2011). These include; Ultraviolet stabilizers; Lubricants; Colourants; Flame retardants; Plasticizers; Antioxidants; Phthalates; BPA; Nonylphenol (Lusher et al., 2017; Yogui et al., 2009; Tsuguchika et al., 2001). Microplastics also play a role in transferring persistent organic pollutants adsorbed to their surfaces. In a number of studies microplastics were shown to have rather high amounts of harmful substances such as polycyclic aromatic hydrocarbons, polychlorinated biphenyls, dichlorodiphenyl-trichloro-ethanes, perfluoro-octane-sulfonate and perfluoro-octane-sulfonamide (Lusher et al., 2017). These substances are found as pollutants in the environment while also being attracted to and adsorbed by microplastics that are found in the same environment as the pollutant. The consequences of ingesting these particles has been studied in small invertebrates and fish and has been shown to have detrimental effects under laboratory conditions, however, in a natural setting the ingestion of these chemical laden microplastics may not have the same affect at least to humans which are exposed to relatively few of these (Lusher et al., 2017; Batel et al., 2014). Microplastics also exist as microfibres from polyester and nylon clothing which once washed, these items of clothing release tiny fibres which are washed down the drain and reach the same fate and consequence as microplastics (Vianello et al., 2018).

2. 1. 1. Top 5 plastics found in waste

2. 1. 1. 1. Low Density Polyethylene (LDPE)

LDPE has a Society of Plastic Industry (SPI) resin ID code 4. LDPE was developed in 1939 by an accidental leak of trace oxygen during an experiment to reproduce polyethylene. It is produced by the ICI process for producing ethylene and is a thermoplastic (Gilbert, 2017). LDPE has a density range of 0.917-0.930 g/cm. It is a flexible but tough plastic that can undergo temperatures of up to 80ºC (Lusher et al., 2017). When compared to High Density Polyethylene it has roughly 2% more branching on its carbon atoms which means it has weaker intermolecular forces. This in turn translates to higher resilience but a lower tensile strength, it also has a lower density due to its molecules being less tightly packed and also has fewer crystalline molecules due to the side branches. It produces methane and ethylene when exposed to solar radiation. This material is used for an array of products such as containers, six pack rings, juice and milk cartons, computer hardware and hard discs, playground slides, plastic hinges on shampoo or ketchup bottles, plastic wraps and corrosion resistant work surfaces (Trapathi, 2001).

2. 1. 1. 2. Polypropylene (PP)

PP has an SPI resin ID code 5 meaning it is recyclable. Polypropylene is also a thermoplastic polymer with many applications. It is produced from the monomer propylene using chain growth polymerisation. PP is very similar to polyethylene with a density between 0.895 and 0.92 g/cm^3. It is a tough and flexible material especially when copolymerised with ethylene. It can be used as an engineering plastic and when discovered was produced in large amounts, competing with materials such as acrylonitrile butadiene styrene (ABS). It is a very economical plastic with good fatigue resistance, it has excellent resilience against many forms of stress such as impact and freezing, it is also resistant to corrosion and chemical leaching. Polypropylene has many uses but is most famous for its plastic living hinges however can also be used in clothing, stationary, packaging, carpets, clear bags, piping, in areas where other plastics may melt propylene will not. Many medical devices are made from PP (Gilbert, 2017; Malpass, 2010).

2. 1. 1. 3. Polyphthalamide (PPA)

Polyphthalamide (PPA) belongs in the polyamide (nylon) family and is in fact a subset of thermoplastic synthetic resins characterized when 55% more moles of carboxylic acid portion of repeating units in the polymer chain are comprised of a combination of terephthalic (TPA) and isopthalic (IPA) acids. The backbone of this polymer made from aromatic acids means that this material has a very high melting point, chemical resistance and stiffness. This means that PPAs have a better chemical resistance, higher strength and stiffness even at higher temperatures, they resist creep and fatigue, have good resistance to warping and also have good dimensional stability while not being sensitive to moisture absorption (Malpass, 2010).

2. 1. 1. 4. High Density Polyethylene (HDPE)

HDPE stands for high density polyethylene It is an often-recycled plastic with an ISO resin code of 2. HDPE is a thermoplastic polymer produced from the monomer ethylene. It is mostly used for plastic bottles, packaging and piping as it has a high strength to density ratio. The density of HDPE can range from 930 to 970 kg/m^3. HDPE has a slightly higher density than LDPE but has much less branches which means it has stronger intermolecular forces and tensile strength than LDPE. It is a harder plastic and less transparent and can also undergo higher temperatures (120ºC) for short periods of time. However, it cannot withstand an autoclave.

It has a wide range of applications some of which are; water pipes, wood plastic, plastic surgery skeletal and facial reconstruction, shampoo bottles, sewage mains…etc (Nagar, 2006).

2. 1. 1. 5. Polyethylene (PE)

PE has an ISO resin code of 1. There are several kinds of polyethylene as described above. It is a thermoplastic although it can become thermoset if modified. PE has a low strength, hardness and rigidity but can be modelled into many shapes. It has a low melting point around 105ºC, but temperatures melting temperatures can vary. It is very chemically stable and is not affected by strong acid or base or minor oxidizing agents. It is not readily degraded but some bacteria have been known to degrade this plastic, it can also become brittle when

exposed to UV light. It is a very good insulator and it has massive application opportunities in packaging, drink bottles, 3D printing, thin solar cells and cellotape (Nagar, 2006).
ISO Resin codes can help the consumer figure out whether a plastic is recyclable or not however there is much consumer confusion when it comes to what they indicate and also many plastic products are made of more than one plastic type meaning they are more difficult to recycle (Gilbert, 2017).

2.2. Degradation of plastic polymers

Degradation of plastic is defined as reducing the molecular weight of the polymers within the plastic material (Andrady, 2011). Plastic is well known for its durable and stable nature and these characteristics make the degradation process in the environment incredibly slow and what has lead to plastics persisting in nature when not disposed of correctly. Plastic polymers which make their way into the environment are exposed to many different types of weathering influences and there are five main methods through which plastic undergoes degradation, usually named owing to the process which classified the cause of the degradation (Andrady, 2011; Bellas et al., 2016; Gewart et al., 2015) that is through:

a) hydrolytic degradation- reacting with water;
b) exposure to heat or thermooxidative degradation – a slow process involving oxidative breakdown in a moderate temperature range;
c) thermal degradation – degradation involving high temperatures which are not normally present in the environment naturally;
d) photodegradation through UV light exposure;
e) biodegradation within microbial cells by cellular enzymes.

Due to their larger surface to volume ratio microplastics usually degrade faster than larger meso- or macroplastics. This is because their polymer surface is exposed and prone to breakdown by chemicals or enzymes. The result of degradation at the surface is for the inside to become exposed for degradation and this results in the plastic becoming brittle and disintegrating into smaller particles or flakes (Hayden et al., 2013).

Most often this process begins with photodegradation due to exposure to UV light from the sun, which gives the initial energy required to incorporate oxygen into the polymers. Plastic polymers begin to degrade in an aerobic environment, this will inevitably lead to thermodegradation. The plastic polymers over time become more and more brittle and and break into smaller particles as the polymer chain decreases in molecular weight. This process will then lead to biodegradation by microorganisms. These microbes convert the polymer chains into biomolecules or carbon dioxide. This process takes a very long period of time, up to 50 or more years to fully degrade, however, there is dispute as to whether these polymers ever fully degrade as some scientists believe they can persist in the environment or landfill sites indefinitely. Low temperatures and oxygen availability, such as conditions in the ocean or in river ways can greatly lengthen the degradation time of any plastic material (Hayden et al., 2013; Andrady, 2011). This is why plastic can persist for long periods of time in landfill and in the ocean as there is less oxygen and it is subjected to cold temperatures (Bonhomme et al., 2015; Andrady, 2011).

2. 2. 1. Biodegradeable plastic

The invention of “bioplastic” has arisen alongside the increasing need for alternative materials to plastic with a shorter and more efficient degradation time. There have been three main types emerging thus far, these include;

1. oxo biodegradable plastic which contains polyolefin plastic, and this contains metal salts in small amounts that aid the degradation process.
2. biodegradable plastic that can be broken down into water and carbon dioxide by microorganisms
3. bio based plastics which are made from biological and renewable sources, within them is a weaker polymer structure which leads more readily to degradation when compared to the plastics currently in use.

Many of these plastics are now available and labelled often as “compostable”, however, they must first reach compost and little research has been done on their degradation time and effect on the environment (Lusher et al., 2017).

2.3. Plastic Waste Disposal

Currently plastic follows three routes of disposal.

2. 3. 1. Burying in Landfill

Landfill is defined as the burying of waste on excavated land. This has got obvious negative connotations as it is using land that could otherwise be used in a more profitable way such as for forestry or agriculture. Burying plastic in landfill leads to very slow degradation as the environment lacks oxygen and plastic degrades better in an aerobic environment, this slow degradation means that the land is therefore not viable for many years (Hayden et al., 2013; Andrady, 2011; Nageotte et al., 2006).

There is another problem with burying plastic in landfill in that some plastics can leach pollutants as they degrade (Zhang et al., 2004). These pollutants include and are not limited to volatile organic chemicals such as xylene, benzene, toluene, ethyl/trimethyl benzenes and bis phenol A (BPA) a compound used widely in many plastics and resins (Lusher et al., 2017; Urase et al. 2008; Xu et al., 2011; Henry, 2019). These compounds are a cause for concern if they are continuously being exposed to the environment through the dumping of large amounts of plastic in landfill, however, it is BPA that has been under the most scrutiny in recent years.

BPA has been linked to numerous health risks and some research has shown that BPA can leach into food, beverages and the soil from containers that are made with BPA. Exposure to BPA has become a particular concern because of possible side effects on the brain and prostate gland of fetuses, infants and children, even being linked to adverse behaviour in children. BPA has also been listed as an endocrine disruptor (Lusher et al., 2017). As well as this when it comes to landfill BPA can leach into the surrounding soil and it has been correlated to increased populations of sulphate reducing bacteria in soil which has lead to a rise in production of hydrogen sulphide, this can have lethal consequences in high concentrations (Tsuchida et al., 2011; Hayden et al., 2013).

2. 3. 2 Incineration

Incineration is the burning of waste products. It is widely used in many countries to some degree. Two positives when comparing to landfill are that there is much less space being used up in this process and in some cases the heat generated from burning the materials may be used for energy, however the negatives include the many pollutants which are released to the atmosphere through the process of burning (Zhang et al., 2004). These include PAHs, PCBs, toxic carbon and oxygen based free radicals, smoke (particulate matter), PCFDs and particulate bound heavy metals. Greenhouse gases, ethylene, methane and CO2 are also released in this process. In some cases the negative effects of the combustion emissions can be controlled by various means; (i) activated carbon addition, (ii) flue gas cooling, (iii) acid neutralization and (iv) ammonia addition to the combustion chamber and/or (v) filtration (Yassin et al., 2005).

Due to landfill and incineration having many negative environmental effects recycling was developed as a potential alternative (Astrup et al., 2009).

2. 3. 3. Recycling

Plastic waste is being produced globally at an ever increasing scale per year and with this comes further pressures on landfill and incineration as disposal methods for the material. This magnifies the environmental drawbacks outlined above with both the space and time needed for landfill and the harmful pollutants produced by each method. Recycling is therefore being investigated as the most sustainable solution for repurposing of the plastic produced each year. Unfortunately, at present only approximately 9% of single use plastics are recycled annually. Not all plastic can be recycled to the same degree and so they must first be separated (Tartakowski, 2010; Hayden et al., 2013).

Plastic materials have various melting points and so if polymers of different plastics are mixed together it can affect the characteristics of the plastic. For example, if HDPE and PP are melted together, they will form a brittle and weak secondary plastic product (Sanchez-Soto, 2008). The key to successful recycling methods is the accurate separating of mixed plastics and grouping of the same materials, there are various ways of separating plastics including; Tribo electric separation, X-ray fluorescence, Fourier transformed infrared technique, Froth flotation method, Magnetic density separation and Hyper spectral imaging technology (Kumar et al., 2017). Recycling can be divided into four main techniques, such as; primary, secondary, tertiary and quaternary. Each has pros and cons to their techniques, however, no matter what material once recycled will forgo some of its properties with relation to tensile strength, dimensional accuracy and wear properties (Kumar et al., 2017).

Recycling can be divided into mechanical and chemical recycling; the types are outlined below.

Primary recycling is also known as re-extrusion or closed loop process (Al-Salem et al., 2009; Sadat-Shojai et al., 2011) this can only be done with clean or semi clean scrap material and is the recycling of a single type polymer which has properties of a virgin material. This method is popular and easy to use and results in a good quality product like to its original. It is a type of mechanical recycling (Sadat-Shojai et al., 2011).

Secondary recycling is also a mechanical type of recycling, it is also a popular choice and is application of choice for many manufacturers. This process usually produces less demanding products and its steps include; cutting/shredding, contaminant separation, flakes separation by floating. After this the single polymer plastic is processed and milled together to make a granulated form, the washing and drying is performed to remove all the glue residue (Kumar et al., 2017; Al-Salem et al., 2009).

Tertiary recycling; Chemical and thermal recycling are the main types featured in tertiary recycling. This type of recycling is beneficial because it extracts the raw materials from which the plastic polymer was created from, such as the petroleum-based products for example. This means that it contributes towards energy sustainability because we are extracting the building blocks necessary to form other plastics. This is achieved through processes such as pyrolysis, cracking, gasification, and chemolysis (Kumar et al., 2017).

The first three types of recycling unfortunately do have their limitations because plastic materials can only undergo 2-3 recycling cycles before it becomes an unviable material, this is where the last type of recycling is utilized. In quaternary recycling waste material is processed to recover energy through incineration, this also leads to reduction of waste and the rest is sent to landfill. This is the best alternative when the plastic has been used to its limits. Although the environmental concerns outlined above are still applicable here (Subramanian, 2000).

2. 4. EU legislation regarding plastic waste

In Europe alone 25 million tons of plastic waste is generated every year with less than 30% being collected for recycling. The 10 most commonly found single use plastic items together make up 86% of all single use plastics and therefore roughly 43% of all marine litter found on European beaches by the latest count, this along with 27% of plastic is discarded fishing gear, together are making up almost 70% of all discarded plastic items found on beaches. European citizens are suspected to be inhaling and consuming microplastic particles on a regular basis as they have been shown to be present in the food they eat, in the air they breath and in the water that they drink, these plastics may have detrimental effects on the health of humans and it is time for the European Union to begin to try and solve or get a handle on the problem (Lusher et al., 2017; Hayden et al., 2013; Geyer et al., 2017).

The reasons and objectives of the Single use plastic directive proposal created by the European Commission are very relevant to this literature review because they highlight the main issues concerned;

a) the fact that plastic litter is building up in the environment especially in aquatic and marine ecosystems through blow off from land-based litter and direct legal and illegal dumping activities,

b) the negative impact on biodiversity of wildlife,

c) the potential hazards to human health which are an increasingly alarming cause for concern and cause for action on the behalf of heads of state (European Commission, COM/2018/028).

Plastics are an integral material in use all over the world, many people and business's depend on plastic daily and life would be very challenging without it. Although due to their durable nature they persist for very long periods of time in the environment and this is having detrimental effects in nature and to human and animal health (Geyer et al., 2017; Hayden et al., 2013).

Another problem with plastic waste is that it often does not remain in one place, it can be moved by the elements in land and sea, through human and animal activity and once in the ocean can move with the currents and effect neighboring countries, this is why a collaborative effort is required in order to tackle this problem effectively. Meetings such as the G7 and G20 and implementations such as the UN Sustainable Development Goals are important in facing this issue on a global scale and hopefully will strengthen its efforts and enhance success rates (European Commission, COM/2018/028).

2. 4. 1. Circular Economy Action Plan

In recent years countries have begun to prioritize action on plastics in the Circular Economy Action Plan, which was adopted in December 2015 in order to help European countries and consumers use plastic in a more environmentally friendly and sustainable way. A circular economy is an economic system that is based on removing the repeated need for raw materials and resources and also cutting down or eliminating completely any waste produced. The backbone of this system is the four "R" principles; reduce, reuse, recycle and repair and plastic products in the future must be designed to fit this model.

Under the new strategy, the European Union will:

1. Make recycling profitable for business

Packaging on plastic will be labelled more clearly in order to improve the ease of recycling and separating plastics when it comes to disposing of them. Across the EU plastic waste will be sorted and separated according to a standardized system. This will add value to the plastic product and help set up a more competitive and resilient plastic industry. This will hopefully be achieved by new rules on plastic packaging.

2. Curb plastic waste

A reduction in plastic bag use has already been seen due to the 2015, Plastic bag directive tax levy. Currently the main area of focus is on single use plastics and fishing gear. Promoting awareness of the problems single use plastic and fishing gear can cause when it reaches the environment as well as restricting the use of single use plastic will encourage the consumer to be more mindful of their use of these items. The Commission shall also take measures to reduce the use of microplastics in various products as well as create more transparent labeling for biodegradable and compostable plastic.

3. Stop littering at sea

New rules will be introduced to make sure that any waste that is generated at sea must return to land to be managed and is not simply discarded at sea.

4. Drive investment and innovation

Guidance for European business' and national authorities on how to reduce plastic waste from the source will be provided by the commission. This will support innovation dedicated to developing more recyclable plastic products, making more efficient recycling processes and removing hazardous substances as well as tracing any contaminants from recycled products.

5. Spur change across the world

While the EU will continue to work on its plastic management, they will also link up with other countries for support and inspiration on how to find global solutions and to develop international standards to the plastic strategy.

The "European Strategy for Plastics in a Circular Economy" was introduced in January 2018. This will hopefully change the way products are used, produced, recycled and designed within the EU. New research can be carried out with regard how many times a plastic can be recycled or breaks down while emitting less harmful contaminants into the environment. This will encourage various companies to be creative with their plastic use and design and can create opportunity to add value in the industry.

If this strategy is implemented correctly it could help Europe ascertain its "Sustainable Development Goals" and the climate commitments which were underlines in the 2016, Paris Agreement as well as the EU's own industrial policy objectives. This strategy could lead to a more sustainable production and consumption of plastic materials whilst also helping the EU reduce its marine, aquatic and terrestrial ecosystem litter, reduce greenhouse gas emissions and limit our dependence on fossil fuel.

On March 27th, 2019 the European Parliament published a press release displaying measures proposed by the Commission to reduce marine litter from the 10 most often found single use plastic items on European beaches, and abandoned fishing gear and oxo - degradable plastics. This proposal also tackling single use plastic is a giant step forward for Europe as it highlights the fact that there is a problem with our reliance on single use plastic and linking it to an environmental issue. It is in keeping with the Circular Economy Plan objectives because the very essence of “Single Use Plastic” is completely opposed to the nature of the plan in that it is not “circular” by any means. It uses a great deal of raw material and produces a lot of non-reusable waste.

- A complete ban on items which there are alternative items available in the market such as: straws, cutlery, cotton buds, stirrers, sticks for balloons and many beverage containers that contain expanded polystyrene and all oxo - degradable plastic.
- Reducing the consumption of any food or beverage containers and cups made of plastic
- “Extended Producer Responsibility schemes” which will cover the cost of litter cleans up will be applied to certain products like tobacco filters and fishing gear.
- The introduction of new designs which attach lids to bottles so they are not separate anymore as well as incorporating up to 25% plastic in PET bottles from recycled sources (European Commission, 2018/0172 (COD)).

This Directive was based on the 2015, Plastic Bag Directive also known as the Plastic Bag Levy which was implemented by what is known as placing a tax on consumer behaviour that brought about rapid shift. It is predicted that these new measures shall have a positive effect on the economy and on the environment if implemented efficiently and correctly. We can cut down our carbon dioxide emissions, avoid damage to the environment predicted to cost up to 22 billion euros by 2030 and save consumers an estimated 6.5 billion euros. After approval by the European Parliament, the Council of Minister must finalise the formal adoption. Member states will then have two years to incorporate the legislation into their national law. Below is the European strategy for plastic in a circular economy from the European Commission singling out the top 10 single use plastic items (SUP) which have been found on Europe’s beaches. These top 10 items make up 43% of total marine litter. Fishing gear represents 27% of the marine litter (Fig. 1).

	Consumption reduction	Market restriction	Product design requirement	Marking requirements	Extended producer responsibility	Separate collection objective	Awareness raising measures
Food containers	X				X		X
Cups for beverages	X				X		X
Cotton bud sticks		X					
Cutlery, plates, stirrers, straws		X					
Sticks for balloons		X					
Balloons				X	X		X
Packets & wrappers					X		X
Beverage containers, their caps & lids			X		X		X
- Beverage bottles			X		X	X	X
Tobacco product filters					X		X
Sanitary items: - Wet wipes				X	X		X
- Sanitary towels				X			X
Lightweight plastic carrier bags					X		X
Fishing gear					X		X

Figure 1: (European Commission, 2018/0172 (COD))

2. 5. Environmental Aspects

Microplastics are now known to be accumulating and persisting in the environment in various ecosystems (Andrady, 2011), however, as of yet the true scale of environmental risk remains uncertain (Koelmans et al., 2017b). Microplastics are a growing cause of concern for environmentalist and can be introduced from the environment to an animal directly and indirectly. Directly through accidental consumption by non-discriminate feeding methods or indirectly through trophic transfer and consumption of contaminated animals in the trophic level below (Nelms et al., 2018). Animals consume the microplastics by mistaking them for their own food source, this is because the microplastics can be covered with prey or are similar in size, shape and appearance. Often the plastic can be covered in a biofilm which helps camouflage the plastic and confuse the consumer (Carbery et al., 2018; Naji et al., 2018). Microplastics are not only a concern because of the risks associated with consumption but also due to their ability to transfer pollutants adsorbed to their surfaces, however, whether the amount of these chemicals is enough to drastically interfere with an animal or humans health is still relatively unknown (Batel et al., 2014). In 2016 a report by the UN documented that over 800 animal species were affected by plastic either through ingestion of entanglement. This figure has risen by 69% since a similar study was carried out in 1977, where only 277 species were seen to be contaminated (UNEP, 2016; Murray and Cowie, 2011).

In a food chain or ecological pyramid there are several levels of succession. These are known as “Trophic levels”. The ingestion of plastic occurs within many different trophic levels (Smith et al., 2018; Boerger, 2010). Beginning at trophic level 1 with primary producers which are organisms that have ability to carry out photosynthesis and therefore produce their own energy and food using sunlight. Following this is trophic level 2; this level is occupied by organisms which feed on the plants known as herbivores, the next trophic level 3 is occupied by an omnivorous or carnivorous predator and usually trophic level 4 or 5 is filled by the apex predator. Usually the last trophic level is occupied by decomposers also known as “detritovores” (O’Callaghan, 2013).

Typically, there are four to five trophic levels in any ecological system. When one organism consumes another energy is transferred through the trophic levels, this is known as “Trophic level transfer efficiency”. Energy will decrease as we move further up the levels. The concern of this review is to explore whether or not microplastic can be transferred through the trophic levels and what is the consequence of this interaction (O’Callaghan, 2013).

Studies have been carried out depicting the trophic transfer in both wild animals and animals subjected to microplastic exposure under laboratory conditions which have shown transfer of particles within food webs and throughout trophic levels (Welden et al., 2018; Setälä et al., 2014; Farrell and Nelson, 2013; Nelms et al., 2018).

2. 5. 1. Terrestrial ecosystem

Most of the current research has focused on marine ecosystems while the effects of microplastic have not been so well documented in the terrestrial systems, however almost all of the plastic present in the marine or freshwater ecosystems was first either created, used or discarded on land. This plastic would have faced various environmental influences that would affect its fate and effect on the terrestrial ecosystems and organisms within it. It is said that microplastics may accumulate in terrestrial and continental food webs in the same way as marine or freshwater systems, however, there is more research to be done in this area (Horton et al., 2017; Machado et al., 2018; Jambeck et al., 2015; Lebreton et al., 2017).

Where microplastics were found in the digestive tract of continental birds they were often seen to be much smaller than their usual forage material (Delgado et al., 2017), indicating accidental ingestion or they arrived there through the route of trophic transfer (Zhao et al., 2016).

One of the first quantitative assessments with regards to trophic transfer in terrestrial organisms showed presence of microplastic in soil, earthworms and chicken faeces (Lwanga et al., 2017). There has been evidence to suggest that bioaccumulation of microplastic could be widespread in the terrestrial environment due to the fact that it has been shown to accumulate in yeasts and filamentous fungi (Schmid and Stoeger, 2016) which suggests accumulation or magnification along the soil detrital food web (Machado et al., 2018).

Although the uptake of plastic is at this stage at a very low level, with minimal toxicity it is a concern that the continual and cumulative exposure to microplastics and these toxins could have in the long term, indeed in Lwanga et al. (2017) a growth reduction was observed in earthworms with 150 um of microplastics in their food. This energy loss at the lower level of the trophic cascade affects the energy transfer to the higher trophic levels. This growth reduction could be associated with the poor nutritious quality of the microplastics, or the potentially toxic effects such as damage to the digestive histology and alterations in the gene expression (Rodriquez-Seijo, 2017). Or the exposure to toxic zinc, due to the affinity for zinc to adsorb to high density polyethylene microplastics (Hodson et al., 2017).

An experiment exposing yeasts and filamentous fungi to polystyrene nanobeads resulted in the lethal toxicity and 100% mortality of yeasts and varying effects on the fungi based on their levels of hydrophobicity within their cells (Nomura et al., 2016; Miyazaki et al., 2015). This shows the effect of microplastics at varying trophic levels and it is unknown as of yet the over all affect this will have on the terrestrial food web or chain, however it is known that pollution at any level, especially the subcellular level can incur negative effects later on (Machado et al., 2018).

Nanoplastics are at the moment under closer scrutiny than the larger plastics as these have the potential to adsorb an even larger amount of harmful and potentially toxic chemicals due to their small size and large surface area. If these particles become attached to the external surface of cells, they can influence several membrane processes involved in intracellular homeostasis in an organism exposed to them. An experiment carried out by Miyazaki et al. (2015) displayed how the nanoplastic exposure disrupted the electrostatic interaction between particles and cell walls, which in turn affected the membrane processes of cells. Amine modified polystyrene particles were also shown to affect the lung responses in hamsters and rabbits after exposure by causing peripheral thrombosis displayed after histopathological examination (Hamoir et al., 2003).

Linking these issues to humans as an apex terrestrial organism, an experiment was shown to report changes in gene expression, inflammatory and biochemical responses after nanoplastics exposure (Forte et al., 2016; Galloway et al., 2015). The properties of nanoplastic adsorption are influenced by their surface, size, electric charge and hydrophobic properties (Schmid and Stoeger, 2016).

It is vital that more research is done in the area of terrestrial organisms, trophic cascade and ecosystem interaction in order to display the potential risks involved with biodiversity and ecotoxicological effects of microplastic build up in the food chain. This is important both to predict future negative impacts, how to prevent them and also to develop government policies in order to protect the organisms and ultimately humans from potentially negative or toxic effects (Machado, 2018).

2. 5. 2. Marine ecosystem

Microplastics are found throughout the ocean, from coastal areas, to surface water to sub tidal sediments, sea ice to the deepest gyres, because of this distribution they are available for ingestion to all marine animals, this has been illustrated in a number of studies and experiments (Carbery et al., 2018). There is evidence to suggest that microplastics are transferred from animal to animal through the trophic cascade within the marine ecosystem,

(Fig. 2). This was a pivotal discovery as it shed new light on the potential bioaccumulation and biomagnification of these particles building up inside the marine food web. Microplastics have entered the food chain and if persistent enough could in fact make their way to humans, with yet unknown consequences.

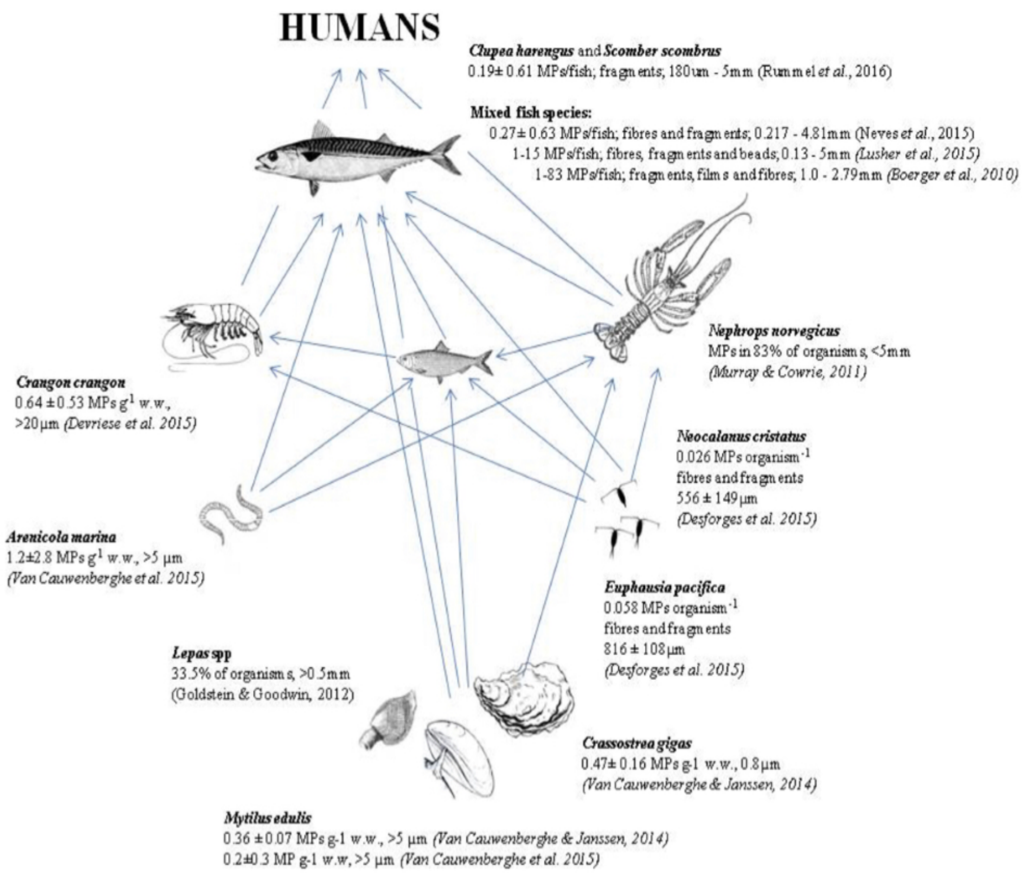

Figure 2: Example of a Marine Food Web (Carbery et al., 2018).

Microplastics are in the size range of plankton and grains of sand, meaning that they are often introduced readily into the food chain by the accidental ingestion by marine invertebrates consuming items of this size as their primary diet (Carbery et al., 2018). They are consumed by a variety of invertebrates including benthic species, selective and non-selective filter feeders, deposit feeders and detritivores (Browne et al., 2011; Van Cauwenberghe and Janssen, 2014). Nanoplastics again are proving to be extremely detrimental to the marine ecosystem and it is also very difficult to quantify. Positively charged nanoparticles have been shown to adsorb to the cellulose in algae, affecting its photosynthesizing abilities, as a primary producer this could have major knock on affects in the marine food web (Battacharya et al., 2010).

One of the first studies which investigated the trophic level transfer of microplastics in marine animals was carried out in 2013 by Farrell and Nelson. The key to this investigation was determining whether microplastics did transfer from one organism to the next via ingestion, to quantify the microplastics transferred and to give a clue as to the persistence of the particles within the organism. This study was done on mussels and crabs and was the first to show "natural" trophic transfer of microplastics from one organism ingesting another. The mussels (*Mytilus edulis*), a very important food for many animals including humans, were exposed to 0.5 um fluorescent polystyrene microspheres. The mussels were then fed to crabs (*Carcinus maenas*). The results showed that the crabs had a maximum amount of 0.4% microspheres that the mussels were exposed to initially. The important discovery was that the microspheres were not only found in the alimentary canal; in the stomach, hepatopancreas, but also in the ovary, gills and even into the haemolymph of the crab from the mussel.

In the 1980s Huntley et al. displayed that zooplankton, a typical marine trophic level 2 consumer, consumed microplastic spheres in place of phytoplankton (Huntley et al., 1980). An experiment carried out on Baltic Sea Zooplankton in 2014 by Setälä et al. showed that microsplastic spheres could also be passed from one trophic level to a higher one; mesozooplankton to macrozooplankton (Setälä et al., 2014; Desforges et al., 2015). This experiment was carried out by feeding fluorescent microspheres to grazing zooplankton. The focus of this experiment was to show direct ingestion of microspheres by many species of zooplankton found in the planktonic web and to verify microplastic introduction into the planktonic food web by then feeding the zooplankton to mysid shrimp and polychaete larvae species.

The ingested particles have the potential to pass through or block the gut, be absorbed or accumulate in the digestive tract and therefore perhaps hinder digestion or feeding. There is also the potential risk associated with chemicals adhered to the microplastics, indicated by Rochman et al. (2014) which revealed the potential for endocrine disruption in fish exposed to the chemicals present in the microplastics, which could have major repercussions for reproductive success and wildlife populations.

It was shown that the mysid shrimp and polychaete larvae ingested the microspheres both directly and indirectly by consuming the zooplankton that had been previously exposed. An important point was raised that since both of these species live in the "pelagial and benthic realm" it is possible for both animals to introduce microplastics into both food webs, causing potential harm to multiple species which prey on them (Setälä et al., 2014).

An experiment carried out by Nelms et al. (2018) on captive grey seals (*Halichoerus grypus)* and wild caught Atlantic mackerel (*Scomber scombrus*) indicated that roughly half of the scat samples and a third of the fish contained microplastic, with ethylene propylene being the most frequently found polymer in both. This was an important experiment because it indicated that microplastics could be transmitted indirectly to an apex predator and could outline how thorough eating fish humans could also be exposed to microplastics. There is a difference, however, in that humans are more likely to remove the digestive tract of fish and not eat them whole such as the seals do, exposing them to a significantly smaller portion of plastic as the majority of plastic is within the digestive tract of the fish. Humans do eat some marine animals whole, such as mussels and sprats (Carbery et al., 2018).

A study conducted by Carbery et al. (2018) stated that although there had been many lab studies carried out which depict marine animals consuming microplastic and the biological effects this had on the animal in question, experiments had also shown evidence of trophic transfer of microplastics through these marine animals consuming each other, however, these had been conducted under experimental lab conditions and not mimicking actual levels available in the environment. Their paper outlines the importance for more research to be conducted from this aspect. Since plastic is present in many seafood items it did display that humans would be at risk from eating contaminated seafood products, adding to the fact that currently microplastic is not quantified or monitored within seafood being sold to humans it is very difficult to assess the actual risk posed to human health from the marine exposure route. This does raise concern considering medical studies conducted on humans and rats demonstrated movement of polystyrene and PVC particles from the gut cavity and circulatory system (Hussain et al., 2001).

Vethaak and Leslie (2016) also showed that the microplastic particles could cross the placenta and blood brain barrier. It is difficult to say whether humans are being exposed to microplastics from other areas also as they can be present in other food or drink items from packaging or cling film wrap and can even be ingested through inhalation of tiny particles in the air.

It has been displayed that microplastics can be transferred through marine food webs however the effect this has on higher organisms and apex predators is still poorly understood (Carbery et al., 2018).

Table 3

Controlled feeding studies showing adverse biological impacts to marine organisms following exposure to virgin and spiked microplastics of varying polymer type, size and concentration (concn). PS = polystyrene, PE = polyethylene, uPVC = unplasticised polyvinylchloride, PVC = polyvinylchloride, HDPE = high density polyethylene, PP = polypropylene and SW = sea water.

Cohort	Species	MP type	MP size	MP Concn.	Contaminant	Biological effects	Reference
Zooplankton	14 mesozooplankton taxa	PS	7.3 µm 20.6 µm 30.6 µm	20 µL/20 mL SW (0.1% v/v)	–	Reduced feeding by *C. typicus*	Cole et al. (2013)
	Temora longicornis *Centropages typicus*	PS	0.4 µm 1.7 µm 3.8 µm	12 µL/24 mL SW (0.05% v/v)	–		
Amphipods	*Allorchestes compressa*	PE	11–700 µm	0.1 g/mL SW	PBDE-28, -47, -99, -100, -153, -154, -183	MPs transferred PDBEs into animal tissue	Chua et al. (2014)
Isopods	*Calanus helgolandicus*	PS	20 µm	75 particles/mL	–	Reduced feeding	Cole et al. (2015)
Polychaetes	*Arenicola marina*	uPVC	–	1% 5%	–	Reduced feeding activity, prolonged gut residence time, inflammation and depleted energy reserves	Wright et al. (2013)
		PVC	230 µm	5%	Nonylphenol Phenanthrene Triclosan PBDE-47	Reduced ability to remove pathogenic bacteria and engineer sediments. Increased oxidative stress and mortality.	Browne et al. (2013b)
		PS	400–1300 µm	0–7.4%	PCB18, 20, 28, 29, 31, 44, 52, 101, 105, 118, 138, 143, 149, 153, 155, 170, 180, 194, 204, and 209	Reduced feeding activity and weight loss	Besseling et al. (2013)
Mussels	*Mytilus edulis*	PS	2 µm 4–16 µm	0.51 g/L	–	Particles observed in the hemolymph, translated from the gut to the circulatory system within 3 days	Browne et al. (2008)
		PS	3 µm 9.6 µm	15,000 particles/ 350 mL SW	–		
		HDPE	< 0–80 µm	2.5 g/L	–	HDPE observed in gills and digestive tissue, strong inflammatory response.	Von Moos et al. (2012)
	Mytilus galloprovincialis	PE/PS powder	< 100 µm	20 g/L SW	Pyrene	Reduced lysosomal membrane stability, genetic effects, reduced AcChE in gills, reduced antioxidant defences	Avio et al. (2015a)
Oysters	*Crassostrea gigas*	PS	2 µm 6 µm	0.023 mg/L	– –	Feeding modifications, reproductive disruption and significant impacts on offspring	Sussarellu et al. (2016)
Crab	*Carcinus maenas*	PP fibres	1–5 mm	0.3–1%	–	Reduced feeding activity and reduction in energy available for growth	Watts et al. (2014)
Fish	*Pomatoschistus microps*	PE	1–5 µm	18.4 µg/L 184 µg/L	Pyrene	Increased mortality, reduced antioxidant defence, reduced AChE activity	Oliveira et al. (2013)

Figure 3: Above is a summary of experiments carried out on various marine animal species and their biological effects (Carbery et al., 2018)

2. 5. 3. Freshwater ecosystem

In comparison to marine ecosystems aquatic freshwater ecosystems have been less examined from the aspect of trophic transfer in food webs but there is new research beginning to emerge in the last few years. The threats in freshwater systems are the same as with terrestrial and marine and in fact recently microplastics have been found in lakes, rivers and estuaries all over the world. They are also thought to be an important contributor of terrestrial litter to the marine ecosystems. From the Danube it is estimated that over tons of plastic is deposited into the Black Sea annually (Free et al., 2014; Lechner et al., 2014). Microplastic ingestion by freshwater invertebrates has yet to be displayed outside of a lab experiment (Hurley et al., 2017).

An experiment carried out by Batel et al. (2016), conducted on *Artemia sp.* nauplii and Zebrafish *Danio rerio* aimed to display how microplastics had the potential to transfer and accumulate along the artificial food chain in aquatic environments and to explore whether the harmful substances are transferred along with the plastics in an artificial food chain created under laboratory conditions. The results of the experiment showed that it is true that microplastics are transferred along with their associated chemicals through the various trophic levels. This experiment was important in displaying trophic transfer from an invertebrate to a vertebrate animal, however, the experiment displayed that the microplastic highlighted with fluorescent dye passed almost completely through the Zebra fish without much evidence for accumulation or absorption through the enterocytes or epithelial cells and also showed no evidence for severe disease to the zebrafish (Batel et al., 2016).

In Manchester an experiment showed that *Tubifex tubifex* worms ingested microplastics and microfibres under lab conditions at varying concentrations. These worms were shown to ingest and tolerate very high concentrations of plastic, much higher than was shown in other freshwater or marine invertebrates. Therefore, meaning they had the potential to pass on large quantities of plastic through the trophic levels. These worms are at the bottom of the food chain as it is a food source for many larger invertebrates such as leeches as well as small fish, salmon and trout which are a link to the human food chain (Hurley et al., 2017).

2. 5. 4. Microplastics in fish of commercial interest

The main focus of this literature review is to explore how plastic enters the marine or freshwater ecosystems, how it can infiltrate food webs and what harm this may cause to humans and animals (Holman et al., 2013). Humans may be exposed to microplastics through various routes, however, a point of interest for this literature review is how microplastics may be taken up by the ingestion of fish and bivalves of commercial interest. Either fish farmed in fisheries, aquaculture centers or wild caught fish.

Fisheries and aquaculture centers have often used plastic in many forms such as ropes and netting, boat construction, boat maintenance, fish hold insulation, fish crates, seafood packaging and transportation, floats, fish crates and boxes, fish cages, pond lining, fish feeders, fish tanks.

Often netting and structures for catching fish are kept buoyant by different types of plastic buoys. Sometimes these structures break free or get lost in stormy weather conditions or when they become too old are simply discarded into the waterways such as oceans, lakes and rivers. Abandoned, lost or otherwise discarded fishing gear (ALDFG) are said to be the most prominent form of plastic waste in the marine and freshwater environments, however, to date there are no definitive numbers for the amount of ALDFG waste in these environments. These materials become marine litter and cause problems for animals that become entangled in the fishing gear, ropes and netting. This plastic also breaks down to smaller plastic particles (Lusher et al., 2015).

There are many other sources of plastic in waterways, however, ALDFG has been shown to be a considerable contributor to marine and freshwater plastic waste.

It has been shown that animals from aquaculture centers are ingesting microplastics also (Renzi et al., 2018; Cheung et al., 2018). The most prone organisms to this are bivalves which have been cultivated in lagoons or estuaries contaminated with plastic (Lusher et al., 2017).

The potential for microplastics to interfere with the fishery and aquaculture industry is a cause for concern for humans both economically and with regards to the health of the consumer. Indeed, it is a threat to food hygiene and safety if we are marketing animals in the marine and aquaculture industry for human consumption which may be contaminated with harmful chemical containing microplastics or fibres. There is minimal information with regard the impact of microplastics upon freshwater ecosystems which means it is difficult to accurately assess and project the affect they will have upon aquaculture and freshwater fish species. There is the potential risk for food safety concerns and also for the revenues of fishery and aquaculture centers (Medrano et al., 2015).

Many species of commercial fish consumed by humans have been shown to have ingested microplastic. These species include but are not limited to,

- Atlantic cod (*Gadus morhua)*
- European Pilchard (*Sardina pichardus)*
- Red mullet (*Mullus barbatus)*
- Atlantic horse mackerel (*Trachurus trachurus)*
- European Sea bass (*Dicentrarchus labrax)*
- Bivalves (mussels and oysters, *Mytilus edulis and Crassostrea gigas)*
- Crustaceans (Brown shrimp)

(Bessa et al., 2018; Lusher et al., 2013; Güven et al., 2017; Van Cauwenberghe and Janssen, 2014; Devriese et al., 2015; Avio et al., 2015b; Brate et al., 2016).

In 2014 Van Cauwenberghe and Janssen carried out research to explore the relationship between the ingestion of seafood and exposure to microplastic particles. Their results are summarized as such;

- European countries with high consumption of shellfish had average consumer levels of up to 11,000 microplastic particles per year. This was found in Belgium who had the highest per capital intake of microplastic particles in which the average intake was 72.1 g/day.
- European countries with very low consumption of shellfish had levels of approximately 1800 microplastic particles per year. This was countries like France and Ireland who had approx. 11.8 g/day consumption rates.

These two scientists focused on Mussels *Mytilus edulis* and Oysters *Crassostrea gigas* and displayed how they were a source of plastic exposure to humans but there are also other species and sources which pose a similar hazard (Van Cauwenberghe and Janssen, 2014).

Initially, it was believed that commercial fish especially those that are farmed in managed centers and fisheries may not be exposed to the same amount of plastic as wild fish. However, a study carried out by Hanachi et al. (2019) in Germany, showed through fourier transform infrared spectroscopy that microplastics were present in high quantities of fish meal being fed to fish farmed in aquaculture centers. This indicates that fish kept in this way may actually be at a higher risk of exposure to microplastics than their wild counterparts as they are sometimes being directly fed microplastics and have no other alternative non contaminated food source. There was a positive relationship between the microplastics levels in fish meal and the plastic found to be ingested by the *Cyprinus carpio* which underlines the theory that fish meal created from marine sources may be a way in which plastics are introduced to cultured fish and thus the human food chain. During the experiment careful consideration was given to plastic contamination from other sources and so special measures were taken to ensure this did not happen. Upon examination, microplastics were discovered in the GI tract and the gills; naturally GI tracts contained the highest concentration of microplastics in comparison to the gills. The most common plastics found were identified as polystyrene and polypropylene. This study is very important in proving another way in which humans may be exposed to microplastics and how the plastics themselves are a human health and food safety risk (Hanachi et al., 2019).

There has also been evidence of fish and other farmed animals such as shrimps being fed meal made from other animals including other fish which contained plastic as above (GESAMP, 2016). Food which has been sold for human consumption has been identified as containing microplastic, this has included fish and shellfish purchased in fish markets (Neves et al., 2015; Li et al., 2016).

When investigating Shrimp consumption, it was discovered that up to 175 microplastic particles were estimated to be consumed per person per year (Devriese et al., 2015). Where mussels are consumed by humans Vandermeersch et al. (2015) discovered that the *Mytilis edulis* and *Mytilus galloprovincialis* from Denmark, France, Spain, Italy and The Netherlands all contained microplastic particles. In Belgium, a country that has very high shellfish consumption rates it was found that in every 10 g of mussels at least 3 to 5 microfibres were discovered (De Witte et al., 2014). In China a study was conducted on microplastic presence in bivalves for commercial use and human consumption with interesting results. The study reported that per gram of bivalves there was 2-11 microplastic particles and figures varied from 4-57 items per individual bivalve (Li et al., 2016).

In the Persian Gulf, five shellfish species were found to have between 3.7 and 17.7 microplastic particles per individual (Naji et al., 2018).

In the Mediterranean microplastics were found in the stomachs of important commercial fish (Romeo et al., 2015) and also in the liver and gastrointestinal tract of sardines and anchovies which are usually consumed whole (Collard et al., 2017; Avio et al., 2015b). Commonly microplastics are found in the stomach and gastrointestinal tract and since this portion is removed in the seafood preparation process it is logical to expect that a consumers exposure to plastic particles is greatly reduced (Wright and Kelly, 2017) and so fish which we consume in its entirety such as sardines, sprats and other juvenile fish pose a more urgent threat however, there is evidence to suggest that microplastic particles also migrate through to the muscles and other eviscerated parts of the fish. This was found in two species used for dried fish consumption; the (*Chelonia subviridis, Johnius belangerii)* which was found with much higher levels of microplastic particles in its viscera and gills. Proving that eviscerating in some cases does not remove the microplastic ingested by human consumers (Karami et al., 2017a). Abassi et al. (2018) also noted microplastic in the muscle of another important commercial fish and crustacean. Although this is less common it does show that more research is needed to understand the transit of microplastic in commercially important fish worldwide and determine what risks to human food safety are involved (Abassi et al., 2018).

A study conducted in Makassar, Indonesia and California, US indicated that fish and shellfish being sold to the public for human consumption contained plastic. The study showed that in Indonesia 28% of individual fish and 55% of total fish sampled contained microplastic. Likewise, in the US 25% of individual fish and 67% of totally fish sampled contained microplastic. In Indonesia the debris found was seen to be mostly microplastic whereas in US the debris was mostly microfibres. Debris was also found in 33% of shellfish sampled. This was a pioneering study indicating that fish being sold to the public where contaminated in plastic. It was noted in the study that both Indonesia and the US rank highly when it comes to poor management of anthropogenic waste (Rochman et al., 2014).

Microplastics were also noted to have contaminated eleven out of twenty-five most important species of fish which are part of the global marine fisheries, this raises a concern because as of yet not enough study has been done to show the interaction with humans and microplastics and it is an area that needs urgent attention from food safety authorities and the World Health Organisation expert committee on food additives (Lusher et al., 2017; Barboza et al., 2018a; FAO, 2016).

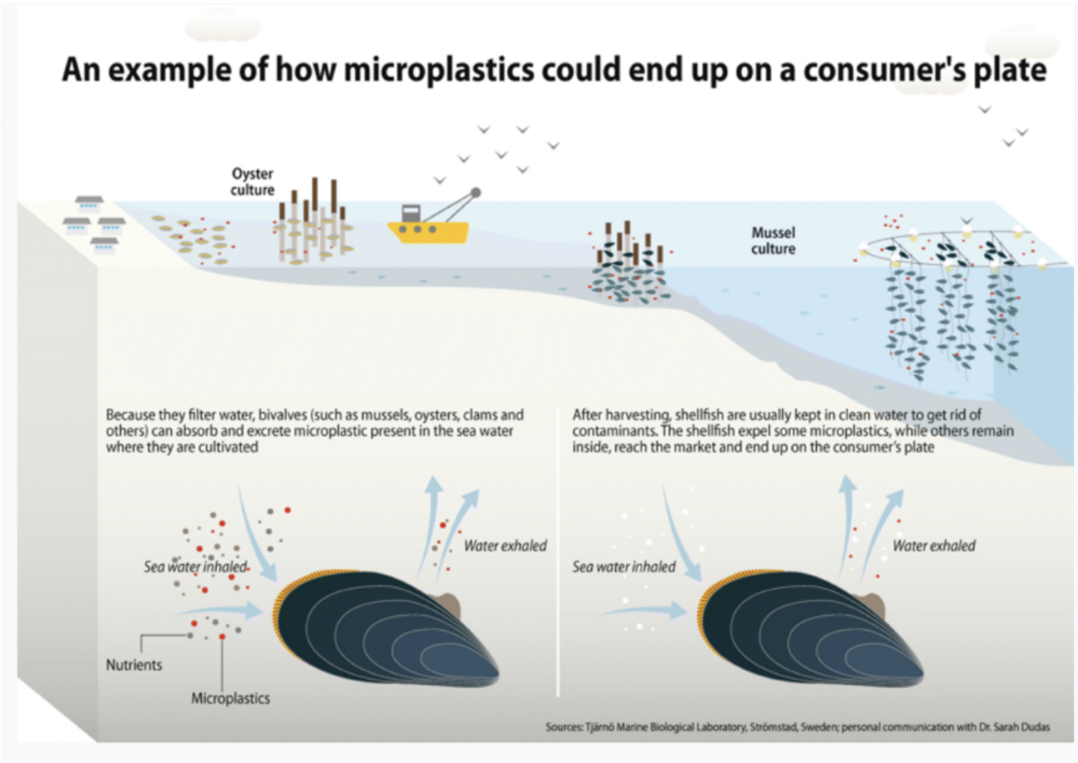

Figure 4: An example of how microplastics could end up on a consumer' plate (Smith et al., 2018).

2. 6. Food safety aspects

2. 6. 1. Adverse effects

Adverse effects have been shown in various marine, freshwater and terrestrial organisms directly or indirectly caused by exposure to microplastics in laboratory conditions. These effects have included;

- mortality (Luis et al., 2015; Gray and Weinstein, 2017),

- feeding, body and metabolic rate (Welden and Cowie, 2016),
- reduced allocation of energy for growth (Farrell and Nelson, 2013),
- decreased predatory performance (de Sa et al., 2015),
- changes in behavioural responses and reduced swimming performance (Barboza et al., 2018a),
- decreased fertilization and larval abnormalities (Martinez-Gomez et al., 2017),
- neurotoxicity due to acetylcholinesterase inhibition and oxidative stress (Avio et al., 2015a; Oliveira et al., 2013; Barboza et al., 2018a; Ribeiro et al., 2017),
- intestinal damage (Peda et al., 2016),
- other several adverse effects (Foley et al., 2018; Wright et al., 2013).

Whether or not these effects will be seen in many humans is still a matter of discussion and yet to be proven (Cheng et al., 2013; Eerkes et al., 2015).

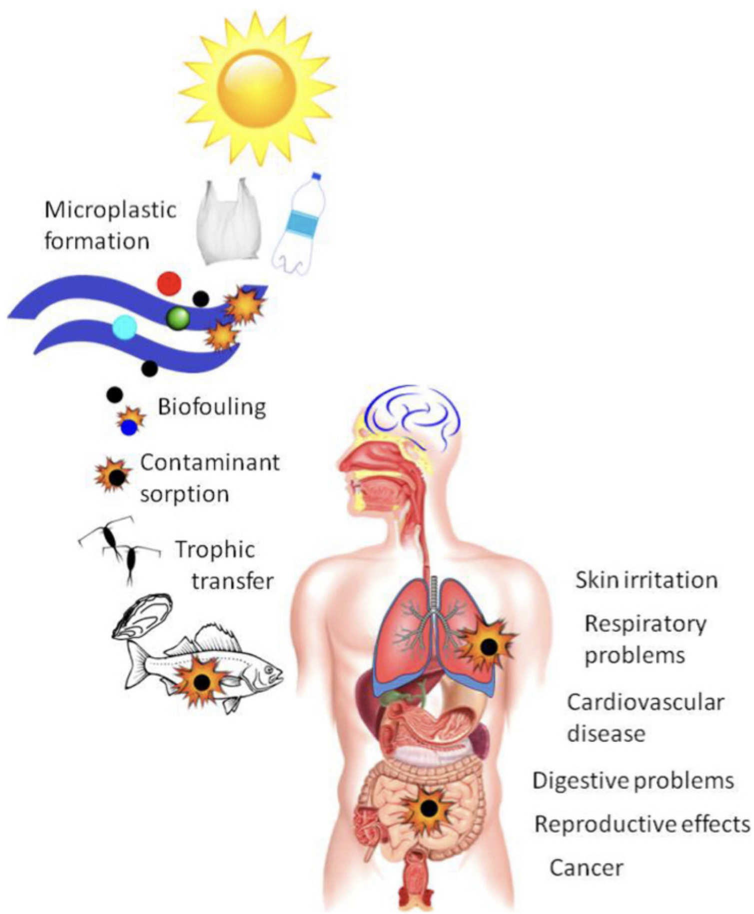

Figure 5: Potential effects of microplastic on humans (Carbery et al., 2018)

2. 6. 2. Potential effect on humans

Microplastics have been found in many foods such as beer, salt, honey, sugar etc. although most studies have been carried out on seafood (Barboza et al., 2018a). Microplastics have also been found in the faecal matter of human beings thus proving that we are being exposed to these particles and also that one of their intake routes is ingestion (Schwabl et al., 2019).

The main focus of this review was to investigate the evidence available and determine the main risks to human health associated with the ingestion of microplastic particles. It has been shown in numerous studies that shellfish and fish of commercial interest are often contaminated with microplastic and it has been proven that this is a potentially reliable source of ingestion exposure to human consumers. It has also been shown in the research that these micro and nanoplastics are laden with chemicals adsorbed to their surfaces and so humans are exposed to these toxicants as a result of ingestion (Barboza et al., 2018a; Barboza and Giminez, 2015; Waring et al., 2018).

Depending on the shape, size, polymer type and additive of the microplastic particle consumed the fate may vary, the plastic may be passed through the gastrointestinal tract unchanged or may be absorbed and distributed throughout the circulatory system (Lusher et al., 2017). From there it can enter cells and tissues and it is at this stage where there is a risk of potentially adverse effects especially if the microplastic particle involved had previously been exposed to chemical contaminants or toxicants of any kind. As mentioned previously these contaminants were either added in the manufacture process or accumulated through exposure in the environment, these adverse effects can be passed from prey to predator and upwards through trophic levels (Wright et al., 2013; Avio et al., 2017; Foley et al., 2018; Chae and An, 2017; von Moos et al., 2012; Peda et al., 2016).

When humans consume food containing microplastics they may uptake and absorb them from their intestinal tracts through the microfold cells (M-cells), Peyer's patches and other lymphatic tissue in the intestines. It is through this action that microplastic can be absorbed into the lymphatic system, however, this depends on particle size. This action has been displayed in many animal models, rabbits, rodents and dogs as well as humans (Hussain et al., 2001). There is mounting evidence and literature to suggest that plastic associated toxic substances can be transferred to exposed wildlife and is a threat to human health through the route of consumption (Van Cauwenberghe and Janssen, 2014).

Although at present there is no data accurately describing the toxicity of translocated microplastics in humans, it is known that these particles adsorb luminal molecules and so have the ability to translocate them to mucosal cells (Powell et al., 2010). It is possible that the particles ingested could incite pro inflammatory and immune stimulatory effects in the gut due to the agents adsorbed to their surfaces. These microplastic particles can then influence effect on the circulatory system, the immune system, the lymphatic system and cell health (EFSA., 2016). These processes would occur due to the fact predicted by Wright and Kelly (2017) that microplastics may cause necrosis to and compromise immune cells, may cause inflammation in tissue and can cause cellular proliferation (Wright and Kelly, 2017).

There is much literature reporting on the organic pollutants and toxicants present in or on plastic found in the marine, terrestrial and freshwater ecosystems (Mato et al., 2001; Endo et al., 2005). Tanaka et al. (2013) described how there is indirect evidence of uptake of contaminants which had been adsorbed into the tissues of sea birds and there is also experimental data from Teuten et al. (2009) which showed transfer of plastic to seabirds' tissues. It is logical to assume that we can expect toxicity from these chemicals and additives, however, the actual effects on humans remains to be investigated fully, the monomers that leach from plastic have potential to cause acute and chronic processes including oncogenic and neurologic effects in the human consumer that is continuously exposed to microplastic particles (ATSDR, 2010). Ingested microplastic have been discovered in the adipose tissue of sea birds and in some lugworms and fish an accumulation of PBDEs were found in their tissues (Tanaka, 2013; Rochmann et al., 2013; Browne et al., 2013). As we gather more research on the effects of wildlife exposed to and ingesting microplastic we are beginning to see the potential fate for the microplastic and human relationship and how the human consumer may be affected by the ingestion of these toxicant and chemical laden microplastic particles (Van Cauwenberghe and Janssen, 2015).

Nanoplastics due to their size and hydrophobic properties mean they can potentially pass through the blood brain barrier, placenta, gastrointestinal tract and lungs which offer sites where damage could be caused (Seltenrich, 2015). Nanoplastics have a large surface area to volume ratio and so this makes them very chemically reactive, if they accumulate enough and have a large concentration of contaminants they have been shown to have various effects after chronic exposure; in vitro in the lungs, liver and brain cells (GESAMP, 2016). Ingestion of nanoplastics has been linked to various effects, like to what is seen in microplastic exposure studies such as: oxidative stress, influence on nutrient absorption, gut microflora alterations, inflammatory responses, reproduction, cardiopulmonary responses, alterations of endogenous metabolites, genotoxicity (EFSA, 2016).

The effect of ingesting micro- or nanoplastics could be caused by either the plastic itself or the associated sorbed toxins, although according to some research the amount at which these particles are consumed through seafoods appears negligible when we take into account the amount absorbed from the gastrointestinal tract and into the tissues. An example provided showed that even if a human consumed a portion of mussels weighing 225 g that the amount of exposure would be roughly 7 μg of plastic. Meaning that the exposure to PBTs or additives would be less than 0.1 percent of the dietary exposure to these compounds. This would indicate that it is unlikely to cause harm to the health of a human being (Lusher et al., 2017). This does not take into account developing countries where rivers are badly polluted with plastic and environmental contaminants where many people rely on fish and seafood as their main source of protein. These people would be at a greater risk to the effects of toxic microplastic particles (McCormick et al., 2014). Although BPA has been found to have potentially harmful characteristics it is still used as a food packaging material additive because it has been registered as "safe" by the European Union, since the European Food Safety Authority have said that it poses no threat or health risk to human consumers at the current exposure levels (EFSA, 2015).

Humans are exposed through the food, water and air (Vethaak et al., 2016). As stated above there have been a few studies that have given insight to the possible risks involved. A study conducted on mouse and human models showed that plastic particles caused lung and gut damage and that nanoparticles could indeed penetrate through the special barriers including the blood brain barrier and the human placenta (Vethaak et al., 2016). Some of the problems included cell damage, inflammation and energy impairment functions (GESAMP, 2015).

Previously it has been stated how microplastic acts as a biosponge attracting chemicals to adhere to its surface. Such chemicals include BPA that has been shown to behave as an endocrine disruptor. However, whether the rate and concentration at which humans are exposed to these chemicals are enough to cause damage are yet to be determined. Nanoparticles have been shown to interfere with cell signaling and uptake processes which could have an impact on the pharmacokinetic properties of various pharmaceutical drug and toxin interactions (GESAMP, 2015).

When microplastics act as a biosponge to human pathogens and parasites, the studies show that harmful bacteria such as *E. Coli*, *Bacillus cereus* and *Stenotrophomonas maltophila* have been found in higher concentrations on the microplastic substrate off the Belgian coast (McCormick, 2014). This would become a bigger issue in countries with poor sanitation and very high populations where wastewater and drinking or bathing water may be in contact. Larger plastic debris is also capable of creating habitats for parasite bearing freshwater snails and so helping their populations increase and spread disease (McCormick, 2014).

Another less direct way that microplastics will affect humans is through their effect on juvenile fish species. In the July edition of the National Geographic 2019 a study carried out on how young fish, crab and shrimp species can sometimes mistakenly feed on microplastics which can lead to malnutrition due to false satiation as well as causing blockages, damage to their enterocytes and death (Fig 6-7). When young fish don't have access to proper nutrition it will lead to inadequate weights of older, mature fish. With marine and freshwater habitats already under stress from overfishing, pollution, ocean acidification etc. it is unhelpful to have another stressor which could affect the delicate juvenile fish and perhaps prevent them from reaching adulthood (National Geographic Magazine, 2019).

Figure 6: Juvenile fish at risk of microplastic ingestion (National Geographic Magazine, May 2019).

1) Hound needlefish 2) Sergeant major damselfish 3) Amberjack 4) Chub 5) Triggerfish 6) Sailfin flying fish 7) Flying fish 8) Man-of-war fish 9) Bigwing halfbeak 10) Mahi-mahi 11) Tropical halfbeak 12) Flat needlefish 13) Large-scaled lanternfish 14) Decapod shrimp larvae 15) Purple pelagic snail 16) Blue shrimp 17) Crab larvae, megalops stage 18) Pelagic snail 19) Blue copepod 20) Medusa (jellyfish) 21) Polychaete worm 22) Blue button hydroid 23) Pelagic sea slug 24) Flatworm 25) Comb jelly 26) Peanut worm

Figure 7: Microplastic particles from various primary and secondary sources (National Geographic Magazine, May 2019).

Most of the plastic found in nets was very small, degraded fragments which are very difficult to identify. 1) Polypropylene or polyethylene fragment 2) Preproduction pellet, polypropylene or polyethylene 3) Braided line from fishing or cargo net 4) Marker-pen cap 5) Monofilament fishing line, nylon 6) Tube for spacing oysters on oyster farm 7) Flexible low-density polyethylene 8) Possible latex balloon 9) Packaging sheet, probably polyethylene food wrapper 10) Expanded polystyrene, probably from a take-out container 11) Soda bottle cap, high-density polyethylene

The amount of micro and nanoplastics present in the environment is going to increase with time following global trends in plastic production if nothing is done to manage their introduction (Geyer et al., 2017). A ban has been placed on microplastics being used as primary additives into cosmetic and cleaning products but there are still the secondary and tertiary microplastics to be concerned about. Human and animal exposure to these microplastics will increase alongside this and it is very important that studies are conducted in a practical and realistic manner in order to accurately discern the risks to human health and safety due to this constant exposure to potentially harmful and toxic particles. It is known that fish provide an excellent source of lean protein packed with nutrients and have many health benefits. However, evidence is emerging that indicates fish are accumulating contaminants from the surrounding environment which now indicates the fact that the fish products could be harmful to human health and safety which thus diminishes and contradicts the health benefits in store when consuming seafood (Lusher et al., 2017).

If this problem has negative knock on affects as are predicted it could have a major impact on humans especially those who rely on fish for their livelihoods or as their main food source.

3. CONCLUSIONS

The main aim of this review was to research the literature and explore the true scope of knowledge available on plastic waste and especially micro and nano plastics and how they are interacting with humans and animals alike. Particular interest was paid to fish in aquaculture centers and commercial fish and seafood to explore whether humans are at a greater or lesser risk from consuming plastic when ingesting these fish. Initially it was thought that fish in aquaculture centers would not be exposed to microplastic because of the nature of their upbringing, however there is evidence that these fish are being directly fed large quantities of marine based feed that is laden with microplastic. Suggesting that their exposure could actually be higher when compared to a natural wild counterpart. From several studies it is evident that humans are ingesting microplastics. The main source of interest to date has been seafood and food of marine source and this is where the majority of study has been done, however, we are ingesting plastic from many more sources. More evidence is emerging outlining the situation in terrestrial and freshwater ecosystems but as of yet, the marine habitat has been focused on moreso. It has been shown how organisms consume microplastic particles and that these particles can be transferred through trophic levels and accumulate in small amounts in higher organisms through indirect means, although the majority will remain in the gastrointestinal tract. Nanoplastics are shown to be more risky because of their nature to be absorbed and how difficult it is to properly assess where they end up or their effect on the human body because of how difficult they are to quantify. They also can adsorb larger amounts of harmful chemical contaminants based on their larger surface area to volume ratio. When it comes to toxicity of these particles it likely is related to dose, size and associated chemicals which have adsorbed to the surface owing to the biosponge properties. Although most microplastics appear to build up in the GI tract there is research showing how they can also build up in adipose tissue of various organisms. Although chemical additives found adsorbed to microplastics include endocrine disruptors such as BPA which are harmful to humans it has been discussed that the amounts they are available may be negligible and cause no harm when ingested and according to UNEP, (2017) they are of no concern to human health and safety. However, more clarification is needed on this issue to determine the real risks at hand. The current knowledge depicts how global understanding is limited based on the sources, bioavailability, exposure, fate and toxicity of microplastic particles and their associated contaminates however the gaps are being slowly filled as research in this area is growing. Simultaneously the amounts of plastic in production and in use and therefore likely to end up as litter is also growing. We must get a handle on this problem before it becomes too heavy a burden. Upon completing the research for this literature review the areas which need developing regarding this topic are the followings;

3.1 Relevant knowledge gaps

- Develop a standardized, reliable quantifying method for microplastics and nanoplastics.
- Identify bioindicator species.
- Develop realistic schemes and policies for waste collection, dumping and recycling, reinvent labelling on plastic packaging items depicting clear recycling and disposal instructions.
- Improve consumer awareness and encourage zero waste initiatives globally.
- Identify more clearly how humans are affected by microplastics and their associated contaminants through toxicological studies and experiments.
- Improve screening of animal feed especially meals fed to fish of commercial interest kept in fisheries and aquaculture centers.
- Develop methods to clean up the environment especially the ocean and create policies to stop dumping and littering of plastic in the ocean, rivers, forests etc.
- Identify clear methods to assess the damage caused by microplastics when they come into contact with a biological organism.
- Identify the risks involved with juvenile fish ingesting plastics and how this may affect fish stocks, especially in areas where fish are the main source of food or livelihood to a community.

There is undeniable evidence that the production of plastic and plastic waste has surpassed necessity and the methods through which these processes are managed globally need redesigning and improving in order to combat the problem at hand. Humans and animals from detritovores to apex predators are ingesting plastic. The cumulative knock on effects of this interaction may have detrimental effects upon humans and animals alike. It is vital that more research is done to discover the potential risk to human health and safety especially regarding ingestion from various sources as the main route of interest. The pinnacle note of interest from this review is that there is simply not enough research available on the relationship between microplastic humans are consuming and the potential toxicity and harm they may or may not cause upon ingestion. It should be prioritized as an area of concern for the global food safety authorities to clarify this issue.

4. SUMMARY

Plastic is ubiquitous in our environment. It has been an incredibly useful and indispensable material in all aspects of human life and without it many advances in medicine, technology or industry would not have been possible, however, the accessibility and low cost of this material has led to global misuse. The chemical makes up of plastic has made it very easy to manufacture but unfortunately difficult to reuse or recycle and the result is that it is thrown away as litter, incinerated or disposed of in landfill. Hence the rise of "single use plastics", of the plastic waste produced between 1950 and 2015 only 9% was recycled.

There are multiple sources of plastic pollution in the environment, from direct littering, drainage systems, landfill waste, ocean dumping, blow off etc. The plastic, once in the environment begins to degrade through weathering and exposure to UV light eventually reaching very small sizes. Many animals mistake these particles for food and so the plastic enters a marine, terrestrial or freshwater food web.

These microplastic particles although chemically inert have been shown to act as tiny "biosponges" for harmful chemicals found in the environment such as PBP (Penicillin binding proteins), fire retardants, microbial drugs etc. changing the nature of a plastic particle from chemically harmless to potentially toxic if ingested in large quantities. Initially it was believed that these particles would simply pass through the GI tract of animals and humans with no biological effect, however studies have shown that they are sometimes taken up and distributed throughout the circulatory system and lymphatic system and may in fact be stored in the fatty tissues of birds, plankton, mussels, fish and even humans.

The result of the uptake of these toxins showed potential carcinogenic effects, liver dysfunction and endocrine disruption in many laboratory experiments.

In this literature review the main focus will be on micro- and nanoplastics and how these tiny particles make their way into marine and freshwater food webs with particular attention to microplastic trophic transfer, their toxic side effects and how they may influence the human consumer in health and safety in the future.

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6. APPENDIX

Figure 1 European Commission. (2018). *Proposal for a directive of the European Parliament and of the council on the reduction of the impact of certain plastic products on the environment.* 2018/0172 (COD). Brussels, 28.05.2018. COM(2018). Page 3. https://ec.europa.eu/environment/circular-economy/pdf/single-use_plastics_proposal.pdf

Figure 2 Example of a Marine Food Web. Carbery., M, O'Connor., W, Thavamani., P. (2018). *Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health.* Environ. Int. Volume 115, Pages 400-409. Page 3.

Figure 3 Summary of experiments carried out on various marine animal species and their biological effects shown. Carbery., M, O'Connor., W, Thavamani., P. (2018). *Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health.* Environ. Int. Volume 115, Pages 400-409. Page 5

Figure 4 An example of how microplastics could end up on the consumers plate. Smith M, Love DC, Rochman CM, Neff RA. (2018). *Microplastics in seafood and the implications for human health.* Curr Environ Health Rep 5:375–386. Page 4.

Figure 5 Potential affects of Microplastics on humans. Carbery., M, O'Connor., W, Thavamani., P. (2018). *Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health.* Environ. Int. Volume 115, Pages 400-409. Page 7.

Figure 6 Juvenile fish at risk of microplastic ingestion from National Geographic Magazine, May 2019 edition. Parker, L., (2019). *Fish nurseries off Hawaii are now a microplastic mess.* National Geographic Magazine. May edition, 2019. https://www.nationalgeographic.com/magazine/2019/05/microplastics-impact-on-fish-shown-in-pictures.

Figure 7 Microplastic particles from various primary and secondary sources from National Geographic Magazine, May 2019 edition. Parker, L., (2019). *Fish nurseries off Hawaii are now a microplastic mess.* National Geographic Magazine. May edition, 2019. https://www.nationalgeographic.com/magazine/2019/05/microplastics-impact-on-fish-shown-in-pictures.

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