Review

Marine availability and effects of microplastics on zooplankton and its related trophic chain and the potential management axes to reduce it

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ABSTRACT:

Plastic issues are numerous and their effects in oceans are of great concern, especially because of the marine availability and impact under its microplastic form. This review is made to expose the presence and effects of ocean microplastic in zooplankton and the ways of management to control and reduce their intake and effects. Microplastics are nowadays present in each part of the oceans which makes them bioavailable and ubiquitous to this environment. Ocean microplastics are coming from different sources, oceanic or terrestrial because of human activities. It is now verified that organisms from the trophic chain’s base can ingested them. This ingestion is due to many factors as microplastics biometry, forms, concentration. Their effects in zooplankton are actually studying and first results show direct and indirect impact that can impact their life, reproduction and growth. Moreover, it was showed bioaccumulation and biomagnification along the trophic chain without really knowing the impact of these ecological phenomena on organisms. More studies must be done to really understand the problematic. However, results are now sufficient to developed management plans to reduce the intake and effects on microplastics in the ocean and all its ecosystems.

1. Introduction:

Every human on Earth depends directly or indirectly on the ocean (IPCC, 2019). The alarming degradation of ocean quality and the visual impact of plastic pollution increase the interest of human population, governments, Intergovernmental Organizations (IGOs), regional seas organizations, the private sector, environmental NGOs, the media and the scientific community (GESAMP, 2016). The high rate of incoming plastic in oceans are estimated between 4.8 and 12.7 million MT each year (Jambeck et al., 2015). Plastic issues are numerous and their effects in oceans are of great concern, especially with the marine availability and impact under its microplastic form. Microplastic in ocean is known since the early 1970s (Buchanan 1971; Carpenter et al., 1972). Microplastic is a marine ubiquitous and bioavailable contaminant. The total number of particles in oceans is hardly measurable and unanimously accepted. Sources of that microplastic begin to be known and are numerous (Boucher & Friot, 2017). Microplastic ingestion has been
verified for various marine species as turtles, seabirds, fishes, delphine, whales (Botterell et al. 2019, as review). All these species are superior predators and can thrive thanks to primary and secondary productors. Consequently, research in the indigestion of microplastics has expanding since few years. The main subject is to determine: 1 - Whether or not zooplankton is able to ingest plastic particles; 2 - If yes, the characteristics and major effects of these particles; 3 - The oceanic areas where the highest rates of indigestion are recorded. Microplastics are a threat for the marine fauna because of their easy intake in the ocean and of their faculty to absorb and desorb toxic hydrophobic compounds and to vectorize them in the ecosystem (Cole et al., 2011). Issues of zooplankton contamination by microplastics is an essential knowledge gap to assess. After having answered these questions we may be able to establish a link between zooplankton predators and secondary productors to study the impact of microplastics along the food web. Since 2000 studies on microplastic have been rising (Kedzierski, 2017) but are highly dispersed and heterogeneous. This review is made to resume the marine availability, sources and effects of microplastics on zooplankton and its related trophic chain to better understand the issues and evoke the studies that could be conducted and deepen, as well as the management axes that can be developed to reduce the intake in oceans. To proceed we will first report the microplastic ocean distribution, its sources and its bioavailability for marine zooplankton. Then we will describe effects by categorizing them in direct and indirect impacts the review will continue by describing the stage of zooplankton microplastic's transfer along the food web and finally will be conclude by the different ways to manage the intake of microplastics in oceans and so reduce their effects.

2. Bioavailability of microplastics

2.1 World distribution

The presence and abundance of microplastics in ocean are hardly quantifiable for 2 main reasons. First, the size. Definition of the microplastic size is not a scientific consensus and fluctuates in studies between <10 mm, <5 mm, 2–6 mm, <2 mm and <1 mm (Cole et al., 2011). Moreover, the number of microplastics’ quantities in ocean is also a problematic data to collect. It is estimated that more than five trillion pieces of macroplastics and > 250,000 tons are currently floating in the oceans (Eriksen et al., 2014) . It makes the microplastic research work complicated, right from the data collection stage. Second reason is the standardization of methods that may lead to misidentification of plastic or unreliable pollution (Miller, Kroon, & Motti, 2017). Nonetheless, some studies have shown significant results about microplastic presence in particular areas: a high quantity of microplastics have been estimated in Alaska and California (Doyle, Watson, Bowlin, & Sheavly, 2011) and presence of plastic production pellets with an abundance most frequently >1000 pellets m$^{-2}$ have been recorded on beaches of the Malta Island (Mediterranean Sea). There is also an accumulation of plastic debris in oceans gyres, especially in South Pacific subtropical gyre. It has been studied using satellite-derived sea-surface height and wind stress fields with a 1/3° grid from 1993 to 2001 and surface circulation of marine waters (Martinez et al., 2009). In these areas, impact of microplastics pollution could be higher due to the high concentration of plastic caused by their inability to get out of these gyratory currents (Law et al., 2010). One of the highest concentrations in a gyre is located in the North Atlantic one, with 20,328 (±2,324) pieces km$^{-2}$ (Cole et al., 2011). In this same gyre a study (Moore, Moore, Leecaster, & Weisberg, 2001) found 334,271 pieces/km2 of neustonic plastic. Microplastics position in the water columns can greatly differ. Thus, the necessity of correctly estimating the ingestion and effects of microplastics on zooplankton. Plastics consist of many different polymers and, depending on their composition, density and shape, they can be buoyant, neutrally-buoyant or sink (Cole et al., 2011). Low-density microplastics are predominantly found in the sea-surface microlayer. Plastic debris density in the marine environment can increase by accumulating microbial biofilms and further be colonized by algae and invertebrates. The gain of density changes the floatability of particles which then become neutrally buoyant or sink into the column (Cole et al., 2011). This change of density is one of the possible explanations of the presence of microplastics in the deepest marine ecosystems on Earth revealed by Jamieson (Jamieson et al., 2019). In their study, they found microplastics in the 6 deepest hadal pits (Pacific Ocean) each separate between 8640 km and 15 000 km. These distances highlight the geographical
extent in the distribution of microplastics and synthetic particles that are ingested at full ocean depths (Jamieson et al., 2019).

2.2 Sources of microplastics

Microplastic is bioavailable and ubiquitous of the marine environment (Botterell et al., 2019). Many studies have demonstrated that we can find microplastic in every place in the world (Cole et al., 2011). In practically all these studies it is recommended to now understand the sources of that microplastics. It exists two categories of microplastic, primary and secondary. It seems that primaries are represented between 3,7 % and 15,5 % of microplastics and the secondaries between 84,5 and 96,3 % (Kedzierski, 2017). Primary microplastic’s studies are largely dominant in part because it's harder to identify secondary microplastic’s sources. In this review, 4 of the 5 explained sources are primary microplastics.

2.2.2 From households

2.2.2.a Cosmetics

Since the beginning of the XXI century, the industry of cosmetic began to use microbeads of plastic is some products (Kedzierski, 2017). It shows some interesting proprieties as abrasion, sorbent phase for delivery of active ingredients, exfoliation or viscosity (Boucher & Friot, 2017). Their consumption is important and preoccupant as an increasing part of the human population has access to hygiene products using microplastics. A very wide range of hygiene products such as toothpastes, shampoos and skin cleansers use these microplastics (Leslie, 2014). Some studies tried to find the number of microbeads released for each use of this type of cosmetic. According to Leslie (2014), some products contain as much plastic added as ingredients as the plastic in which they are packaged and it could be represents up to 10% of the product weight and several thousand microbeads per gram of product. Napper et al., (2015), based on an estimation, that takes into account that these products are used by around 1.1 million women in the UK once per day and assuming that the typical daily amount used is 5 mL, the release of microbeads could be between 4594 and 94,500. These microparticle of plastic would have the potential to be released during the use and terminate in wastewater of houses. The precedent study concentrate the use of these cosmetics for women but it could lead to an underestimation because classical use of personal care products that results in the direct introduction of the plastic particles into wastewater streams from households, hotels, hospitals, and sport facilities including beaches (Boucher & Friot, 2017). Due to their size (typically coarse, >6 mm, and fine screens, 1.5–6 mm), a considerable proportion is likely to pass through preliminary sewage treatment screens of sewage treatment plant (STP). Thus, these microparticles will enter in effluents and then will be discharged into inland waters, estuaries and oceans (Napper et al., 2015). A try to estimate the real release in the oceans concluded that the emission of microplastics from cosmetics could reach each year 263 tonnes per year in United states of America (Napper et al., 2015). These phenomenon is partially verified by the fact that microbeads from cosmetics have been observed in field studies in different areas of the world (Boucher & Friot, 2017). And it is possible today to affirmed that microbeads of microplastic used in cosmetics are an important primary source of marine microplastics contamination (Napper et al., 2015).

2.2.2.b Textiles

Plastic and more particularly fibres of plastic are used in many everyday objects and materials. One of the sectors that use the most plastic fibres is the industry of textile. Nowadays fabrics such as nylon, polyester and acrylic are now widely used in clothing, carpets, upholstery and other such materials (Napper & Thompson, 2016). Textiles have the potential to release fibres into the environment, and one pathway is via laundering in washing machines. The release is due to the abrasion during the washing, inducing the creation of microfibres (Boucher & Friot, 2017). However, even if the abrasion is the mechanic force of textile destruction other washing machines practices including temperature, the use of detergent and fabric conditioners and the type of textile are factors of microplastic release (Napper & Thompson, 2016). Some studies have estimated the quantity of microfibres released. First in 2011, it was shown that a washing machine produced 1,900 synthetic fibres during the process (Kedzierski, 2017). Then in 2016, Napper &
Thompson estimated, that a typical washing load of polyester-cotton blend (6 kg) releases 137,951 fibres (polyester-cotton), 496,030 polyester and 728,789 Acrylic. They also demonstrated that there were significant effects of wash conditions and type of textile, but no clear picture based on detergents and conditioner. Due to the small size of the fibres, they are not caught by the washing machine filters and so go in the wastewaters of industrial laundries and houses (Napper & Thompson, 2016). Then a considerable proportion could pass through preliminary sewage treatment screens of STP. Because STP waters are discharged as treated effluent and that microfibres from textile degradation are not filtered they are released into the aquatic environments. Hence, there is a considerable potential for fibres from synthetic textiles to accumulate in the environment (Napper & Thompson, 2016). Because these fibres are very similar to those found in sediments, it is possible that a very large proportion of the microplastics found in the environment come from washed fabrics (Kedzierski, 2017). This could explain why significant amounts of these textile fibres have been observed in many in situ sampling studies both in open water and marine sediments (Kedzierski, 2017).

2.2.3 Tyres

Ocean microplastic can come from oceanic plastic degradation or from terrestrial plastic degradation. One of the main source of the second possibility is the degradation of tyres (Kedzierski, 2017). Currently in the world, there are close to 2 billion of cars that running thank you to tyres. Road vehicle tyre tread mainly consist of natural and synthetic rubber that corresponds to plastic (Verschoor et al., 2016). Tyres get eroded when used because of the force of friction (Boucher & Friot, 2017). The total amount of tyre tread material lost per kilometre varies widely and depends on several parameters such as: a) tyre characteristics (tread depth, construction, pressure and temperature, contact patch area, chemical composition, accumulated mileage and alignment); b) vehicle characteristics (weight, distribution of load, location of driving wheels, engine power, electronic braking systems, suspension type and state of maintenance); c) road surface characteristics, (material, texture pattern, wavelength, porosity, condition, wetness and surface dressing); d) vehicle operation (speed, linear acceleration, radial acceleration, frequency and extent of braking and cornering) (Verschoor et al., 2016). It has been estimated in Netherland, that the degradation of tyres during use produces a total of 17,300 tons of microplastics per year (2012) (Verschoor et al., 2016). Synthetics microparticles can then be spread by the wind or washed off the road by rain and could and will terminate in aquatic environments. Verschoor et al. (2016) don’t have exact estimation of the transfer in oceans but have estimated that in the 17,300 t/y, 500 tons of tread wear was emitted directly into surface water (from rural roads and highways) and 2,300 tons into the sewerage system (from urban roads). Because it is difficult to study the oceanic microplastic presence (surface, water columns and sediments) it is harder to determine if found microplastics are coming from tyres. However Norwegian and Swedish researchers have pointed out that a large fraction of particles found in the sea seems to originate from this source (Boucher & Friot, 2017).

2.2.4 Paints and coating

Paints are applied for aesthetic reasons, road security and for their protective qualities. Once applied and dried, paints protect substrates and prolong the lifetimes of ship hull, bridges, metal, wooden construction materials, cars, furniture etc. (Verschoor et al., 2016). Paints are made from a mixture of ingredients that originate from fossil, mineral, biological or synthetic sources. Paints are composed of resin (in majority from petrochemical industry) that hold all the pigment and fillers together, ensure the integrity of the paint-layer and create the adhesion to the substrate (Boucher & Friot, 2017). Some of these resins contain microplastic beads. The sanding of old paint layers or the degradation of the paint layer by natural conditions (weather, oxidation, UV radiation, organism’s colonisation etc) may lead to paint particles being released into the environment under the form of meso- micro- or nano-particles. Emissions of microplastics from paint application, degradation and replacement occur during the entire lifespan of the coating (Verschoor et al., 2016). Three sectors are of main interest and preoccupation about microplastic’s paints release: road markings, marine coating and building construction (Boucher & Friot, 2017). Verschoor & al. (2016) has estimated that in Netherland the sector of construction and road marking emitted 490 tons of plastic microparticles per year (2012) and 200 t/y for the sector of marine coating. Microparticles from first
and second sector may finally reach surface water through wind and rains. Marine coating (secondary microplastic) is directly in contact of aquatic environments and because the big lake of environmental security it is estimated that close of 100% of microparticles emitted could reach the water (Verschoor et al., 2016).

2.2.5 Industrial

Microplastic is used in industry to create larger plastic. It is the primary form of a plastic. These microparticles (2-5mm) are named “pellets” (Kedzierski, 2017). During the transport (maritime or terrestrial), during the manufacturing or the recycling, pellets can be spilled into the environment through the plant’s rinsing or small or large incidents (Cole et al., 2011). It is hard to determine the quantity of pellets lost during the plastic chain value but many field studies are reporting the occurrence of plastic pellets in the aquatic and terrestrial environment and high concentration zones close to industrial zones (Boucher & Friot, 2017; Kedzierski, 2017).

2.3 Ingestion and factors

Because it was demonstrated that it exists many microplastic’s sources and that is bioavailable in the marine environment (Cole et al., 2011), the scientific community searched potential effects of marine organism and particularly in the base trophic chain organism’s, zooplankton.

2.3.1 Ingestion

Microplastic have become an emerging contaminant of concern due to their global abundance and widespread distribution (Desforges, Galbraith, & Ross, 2015). Nowadays, plastic particles are ubiquitous and bioavailable for marine fauna. Bioavailability means the proportion of the total quantity of particles/chemicals present in the environment that is available for uptake by an organism (Botterell et al., 2019). Numerous cases of microplastics ingested by zooplankton have been highlighted by several studies in different geographical localization, deep and species. Between 1986 and 2008, 6,000 plankton samples have been collected in the North Atlantic Ocean and Caribbean Sea. The analyses showed that 60% were contaminated by microplastics (Law et al., 2010). In the northern South China Sea, the Yellow Sea and in the Northeast Pacific Ocean, they used an analytical method based on fluorescent microplastic counting and experiments to evaluate the microplastic ingestion in the brine shrimp larvae, Artemia parthenogenetica. Results revealed that A. parthenogenetica larvae is able to ingest particles of 10 μm polystyrene microspheres (Wang et al., 2019). In the North Pacific Ocean other evidence have been provided that two different species of zooplankton (the copepod Neo-calanus cristatus and the euphausiid Euphausia pacifica) absorb microplastics. The rates resulting from ingestion were 1 particle/every 34 copepods and 1 particle/every 17 euphausiids (euphausiids > copepods; p = 0.01) (Desforges et al., 2015). Confirmation that many taxa of zooplankton ingest polystyrene beads was made by (Cole et al., 2013). In this study, thirteen taxa have ingested beads of a size range from 7.3 to 30.6 μm in experimental conditions. It has been also proved that, even in nine of the deepest hadal pits, microplastic is bioavailable. Hadal pits are between 6948m and 10890m depth and microparticles fibres and fragments were found in the hindgut of amphipods (Lysianassoidae sp.) in all nine sites (Jamieson et al., 2019). According to Jamieson et al. (2019), “there are no marine ecosystems left that are not impacted by plastic pollution”.

2.3.2 Factors of ingestion

A number of abiotic and biotic factors can affect the bioavailability of micro-plastics to zooplankton (Botterell et al., 2019). Many of them are explained in the literature but here we focus on the main five: the size, the color, the shape, concentration of particles and the time of exposure to these particles. Whether these factors are relevant or not, the main assumption is that species at lower trophic levels of the marine food web are mistaking plastic for food (Desforges et al., 2015).
2.3.2.a Size

Generally, zooplankton are non or slightly selective filter feeders. Their diet regime is made of microalgae or smaller larvae. The size of their preys may be very close in size and shape to microplastics. It has been recorded that the brine shrimp larvae, *A. parthenogenetica*, ingested polystyrene microspheres likely owing to similarities in size and shape to their preferred microalgal food (Wang et al., 2019). Two others species, *C. pacificus* and *A. clausi*, were not able to differentiate between microplastic beads and algae of a similar size during feeding studies (Cole, Lindeque, Fileman, Halsband, & Galloway, 2015). Size can play an important role in microplastic zooplankton ingestion, even if there are slightly selective consumers, they are able to change their diet by changing their prey size to avoid microplastic. Under experimental conditions a copepod (*C. helgolandicus*) exposed to control solution ingested all size classes of *T. weissflogi* (microalgae), with a preference for the most abundant 13.8–14.8 μm diameter algae. But Copepods exposed to 20.0 μm microplastics consumed only the smallest available prey, with a preference for algae 12.7–13.7 μm in diameter (*P* < 0.001) in order to try to avoid particles (Cole et al., 2015).

2.3.2.b Color

Few studies concentrate their work on the color of plastic particles even if it can possibly affect zooplankton ingestion (Wright, Thompson, & Galloway, 2013). The color has been described during some analyses of microplastics ingested and main found colors were black, blue, red, purple, pink (Cole et al., 2015, 2013; Coppock et al., 2019; Desforges et al., 2015; Jamieson et al., 2019). It is important to specify that no statistical study was made or if so, ingestion was not significant for one specific color.

2.3.2.c Shape

As color shape does not have a critical effect in the microplastic uptake by zooplankton. However, two shapes of microplastics are relevant. In fact, particles can be fragments or fibres. In the deepest marine ecosystems, a total of 122 ingested microparticles were identified in amphipods and were categorized into fibres and fragments. Fibres were found within every pit and appeared in 84% of amphipods, whereas the occurrence of fragments was lower and appeared in only 16% of amphipods (Jamieson et al., 2019). Ingestion of fibres or fragments also depends on the proximity of an anthropized coast. In the Northeast Pacific Ocean, a gradient of fibres or fragments particles ingested by an euphausiid (*Euphausia pacifica*) has been observed according to the distance of an industrial coast (Strait of Georgia, Vancouver). Microplastic fibres ingested rate decreased with distance from shore, while fragment particle rate rose (Desforges et al., 2015).

2.3.2.d Concentration of microplastic and time exposure

Experiment indicated that for brine shrimp larvae, the rate of microplastic ingestion of 10 mm polystyrene microspheres changes when exposed to different concentrations (10, 102,103 and 104 particles/mL) over 24-h exposure periods. The rate decreases from 0.15 particles/individual for an exposure to 10 particles/mL for 24 h to 0.05 particles/individual when exposed to 1 particles/mL for 14 days. A clear increase in the amount of consumed microplastic particles per individual was observed with increasing microplastic concentrations both over short- (24 h) and long-term (14-d) exposure regimes (Wang et al., 2019). Thus, the connection is made between microplastic ingestion, concentration of microplastic and time of exposure. Desforges et al. (2015) compared ingestion between high microplastic concentration area close to Vancouver and the Strait of Georgia (place of high human activity and plastic contamination) and an area further with less pollution (Desforges et al., 2015). They determined higher levels of ingestion in the Strait of Georgia and northern Vancouver Island/Queen Charlotte Sound than in 600 km further offshore. They suggested that the concentration of ingested plastic is a positive function of available plastic in seawater. Therefore, concentration plays a central role in microplastic zooplankton ingestion. However, lot of studies were made under experimental conditions with high concentration of micro particles exceeding by far
natural concentrations (Cole et al., 2013; Setälä, Fleming-Lehtinen, & Lehtiniemi, 2014; Wang et al., 2019). Too high concentration may not represent reality. This is why it is important to do it with natural concentration (Cole et al., 2015; A. L. Dawson et al., 2018) (Cole et al., 2015; A. Dawson et al., 2018) or using directly ocean samples (Desforges et al., 2015; Jamieson et al., 2019).

3. Effects of microplastics

Studies have shown that the ingestion of microplastics by zooplankton is real, not negligible and can induce accumulation. It may lead to two different impacts categories. 1 - Direct impact: reduced feeding, loss of energetic reserves, reduced fecundity, survival and alteration of the system digestive’s cells (Wright et al., 2013). 2 - Indirect impact caused by a potential transfer of toxic additives and adhered waterborne pollutants (Cole et al., 2015).

3.1 direct impact

3.1.1 Reduced feeding

In different studies, the uptake of microplastics engendered a reduction of prey ingestion. In A. parthenogenetica larvae normal ingestion rate is 7.69 ± 0.15x104 microalgae cells/larva/h and in presence of microplastic exposure (10 μm polystyrene microspheres at concentrations of 102 particles/mL), this rate decreases to 4.7±5.6x104 cells/larva/h. This drop represents 27,2% less ingestion under environmentally relevant concentrations (Wang et al., 2019). Other species, copepod C. helgolandicus ingested 51,500 cells copepod−1 day−1 on average; comparatively, copepods exposed to microplastics ingested 45,700 cells copepod−1 day−1, meaning 11% decrease at low concentration (75 microplastics.mL−1) (Cole et al., 2015). The decrease of ingestion caused a 40% reduction in carbon biomass ingested by copepods exposed to microplastic.

3.1.2 Energetic reserves

The decrease of ingestion rate may induce energetic losses for zooplankton and generate other troubles (Cole et al., 2015). For the copepod, the reduction of ingestion was synonym of extreme energetic losses: − 9.1 ± 3.7 μg C. copepod−1 day−1, two times greater than normal energetic losses. Zooplankton can live few days without lot of preys thanks to their lipid reserves. But presuming microplastics are resulting in energetic deficiencies in copepods, this could lead to rapid consumption of lipid reserves, with repercussions on the health of individuals (Cole et al., 2015).

3.1.3 Reduced fecundity & life span

Cole et al. (2015) studied the egg production of the copepod C. helgolandicus, their number, size and the hatching success. The number of eggs was not significantly different between control individuals and individuals exposed to microplastic. On the contrary, egg size decrease in the latter half of the study, copepods exposed to microplastic produced statistically significant smaller eggs than those laid by control specimens in a nine days experimentation (day 7: 185.1 ± 1.7 μm (control) and 180.4 ± 1.4 μm (microplastic), P < 0.001; day 9: 183.4 ± 0.7 (control) and 179.5 ± 0.9 (microplastic), P < 0.001). The hatches success has been analyzed and they showed a drop from 85.1 ± 8.4% (control) to 63.6 ± 10.1% (microplastic). Eventually, they present the survival rate of copepods and highlight that 5 more copepods died with the microplastic exposure. The energetic losses may be strongly implicated in the mortality.

3.1.4 Cells of the digestive system

One of the main technics to study intestinal tissues cells is to use histological analyses (Wang et al., 2019). First, an abnormal quantity of lipid droplets in intestines of brine shrimp larvae has been observed. Lipid
droplets are dynamic organelles that play an important role in the regulation of intracellular lipid storage used in energy generation, lipid metabolism, and membrane synthesis. (Wang et al., 2019). A too high rate of these droplets may result in deregulation of enzymes and membrane proteins. Secondary observations drew attention to cells modification between control brine shrimp and microplastic test. Many intestinal epithelia cells were deformed, disorderedly arranged and expelled into the lumen. These deformations could be caused by the excessive secretion of particles as enzymes, due to the high rate of lipid droplets. This uncontrolled enzyme number could digest epithelial cells and engender troubles. Modification intestinal cell structure may lead to adverse effects in digestive function, thereby reducing efficiency of nutrients adsorption. (Wang et al., 2019).

3.2 Indirect impact

Plastic polymers including microplastics are good persistent organic pollutants (POPs) and polycyclic aromatic hydrocarbons (PAHs) absorbents and desorbents. This characteristic makes them vectors of toxic hydrophobic compounds and raises the bioavailability of POPs and PAHs for marine fauna and especially for zooplankton (Cole et al., 2011; Ward & Kach, 2009). Plastic particles can easily absorb these molecules and may be ingested by zooplankton and be digested in the end. During the degradation of microplastic to nanoplastics in their digestive system (A. L. Dawson et al., 2018), POPs or HAPs may leach from particles and be translocated through membranes and create organic disturbance (Dias & Pereira, 2016).

3.2.1 Impacts of POPs, PAHs and plastic additives

It has been demonstrated that the rotenone, a polychlorinated biphenyl (PCB) molecule, present on microplastic, can penetrate the cyst wall of calanoid copepod, Boeckella poppei eggs. The entrance of this PCB in the cyst caused lacks of hatching (Reed et al., 2018) and therefore may perturbate the growth of the individual and the healthy renewal of zooplankton population and structures of communities (Dias & Pereira, 2016). POPs transported are a serious threat to the zooplankton eggs bank. Hatching eggs perturbation is worrisome but embryo and larvae development is maybe even more concerning. POP’s impact doesn’t stop there. In fact, they generate abnormalities of development in embryo and larva of the sea urchin Lytechinus variegatus. Experimentations has shown a maximum mean increase of development troubles with respect to control of 58.1%. This experiment was made with virgin pellet composed of primary elements and industrials additives such as emollients, colorants and antioxidants (Dias & Pereira, 2016).). Whereas, another result with different pellets (beach-collected) presented an inferior mean increase of 34.6%. These pellets were beach collected pellets that got the time to leach additives and absorb POPs or HABs. This average is far from negligible but signifies that additives do more damage to organisms than other pollutants that may be adsorbed on plastic polymers (Dias & Pereira, 2016). Both contaminants impact POPs/PAHs and additives in zooplankton are crucial to study because of their ability to be communities or ecosystems modifiers.

4. Effects in the trophic chain

It is clear that zooplankton ingest microplastics and toxic compounds. Both plastic particles and noxious molecules harm secondary productors as we exposed for the brine shrimp larvae (A. parthenogenetica). However, it doesn’t stop there. A. parthenogenetica and especially their larvae are highly vulnerable to predation which would render microplastics more accessible to higher trophic level organisms like fish (Wang et al., 2019). The microplastic and toxic compounds transfers from zooplankton to higher trophic levels is a critic notion with very few knowledges. The direct impact of microplastic in the zooplankton may also have an effect in the trophic food web. The microalgae ingestion rate decrease of the copepod Calanus helgolandicus, its energy losses and high mortality due to microplastic can engender disturbances in the superior predators of the food web because of its statute of keystone prey and its high lipid content (Cole et al., 2015). Biomagnification of microplastic from zooplankton is hard to quantify because of the first step of bioaccumulation, also tough to determine. But assumptions can be made. Desforges et al. (2015) did the first extrapolation in 2015 with their study on the ingestion of Microplastics by Zooplankton in the
Northeast Pacific Ocean, by estimating the number of ingested microplastic by salmon each day, according to the number of zooplankton eaten and the mean of microplastic in these zooplankton. They found 1 particle/every 34 copepods and 1/every 17 euphausiids. Most salmon species feed heavily on copepods and euphausiids during their juvenile and/or adult life phases (Brodeur, 1990). They estimated that in coastal British Columbia, the juvenile salmon probably ingest 2–7 microplastic particles per day\(^1\), and returning adult salmon ingest ≤ 91 particles per day\(^1\). If biomagnification rules are respected across the food web the higher predators of salmons as endothermic fish, marine mammals (toothed whales) and ectothermic fish (Strøm et al., 2019) or even humans may multiply these rates. Then, a replication of this method was made, in the same geographical area, with a high consumer of zooplankton: the humpback whale (Megaptera novaeangliae). Result gave an ingestion of ≤ 300,000 plastic particles per day\(^1\) and per whale\(^1\), regardless of the free microplastics uptakes present in marine water (Desforges et al., 2015). Microplastic transfer along the food web has also been verified with mysid shrimps (M. relicta) (Setälä et al., 2014). After three hours of incubation with microplastic sphere contaminated zooplanktons and after fluorescence analysis, it revealed that M. relicta had fluorescent microspheres inside their intestines. Presence of microplastics along the food web is relatively well known. However, the role of zooplankton can be hard to define without extrapolation. Laboratory experimentation as Setälä et al. (2014) started to explore it but field experimentation is still lacking.

5. Management axes to reduce marine microplastic

Microplastics are nowadays an integral part of the marine ecosystem (Botterell et al., 2019). It is important has recommended to continue qualitative and quantitative researches to better understand this quite infamous subject, among other thing in tropical marine ecosystem where it is practically unknown. However, research is not the unique thing to do to limit the entrance and impact of plastic and microplastic in oceans, it is crucial today to develop real management axes about this topic (GESAMP, 2016).

5.1 General management

One management axe is the national, regional or international legislation thank you to agreements (Kedzierski, 2017). Some of them are focusing in the plastic contamination. The one with best effects is the famous international convention MARPOL (MARine POLlution) created by the Marine International Organization (MIO) in 1978. The V\(^{th}\) annexe allows, in particular, the control of ships that are sources of pollution. The agreement limits the dumping of waste at sea and prohibits the dumping of plastics and other synthetic materials such as ropes, fishing nets and plastic rubbish bags (Kedzierski, 2017). However, despite the international MARPOL agreement, the lack of control and education (Cole et al., 2011) and the reluctance to change practices, which are not without economic cost, still make maritime traffic one of the main sources of marine pollution today (Derraik, 2002). In European Union (EU) it exists one directive that legally binding directive that addresses microplastics. This is the Marine Strategy Framework Directive 2008/56/EC (Verschoor et al., 2016). It mentioned microplastics as one of the indicators for a good ecological status of the marine environment and should oblige member states to develop monitoring methods in order to follow trends in the amounts and occurrence of microplastics, sources of microplastics and on measures that can reduce the quantity of microplastics (Howarth, 2008). One of the most famous monitoring methods developed following that directive is the OSPAR Regional Sea Convention that enable a standardized investigation on opportunities to reduce the emission of microplastics into the environment (Verschoor et al., 2016). At the level of the legislation it exists various ways to act. Command and control instruments (CAC) “the direct regulation of an industry or activity through legislation that states what is permitted and what is illegal” (Baldwin et al., 2011). The Environmental quality standards or setting emission levels are examples of a command and control instrument. The use of CAC is a key issue that must be handled wisely but the costs involved with enforcement may be high (Verschoor et al., 2016). For the microplastic CAC must be developed and applied to ban on certain ingredients or the obligation for industries to use the best available techniques and best environmental practices to minimize microplastic emissions (Verschoor et al., 2016). The other way is the economic instruments. They are “policy approaches that encourage things such as more environmental friendly behavior through their impact on market signals,
rather than through explicit directives focused on pollution control levels or methods or resource use.” (Baldwin et al., 2011). Some examples are emission charges/fees/taxes; user charges/fees/taxes; deposit-refund systems; liability payments (Verschoor et al., 2016). The yields of economic measures could be used to finance generic purification facilities or clean-up activities (Kedzierski, 2017). All these instruments should be used to limit emission of primary or secondary microplastic in oceans, implementing adequate infrastructure and waste management practices (Boucher & Friot, 2017). Verschoor et al. (2016), Boucher & Friot (2017) and Napper (2015, 2016) have emitted many recommendations and solution to reduce the microplastic pollution from various sources (Household, tires, paint and coating, industrial, sewage system).

5.2 Rising awareness

Often, in opposition to activities (industry or consumers) that produce negative effects on the environment the best solution is to raise awareness thank you to many instruments depending on the intended target (Baldwin et al., 2011). In the subject of marine plastic and microplastic, rising awareness is a key component of prevention. It can be used in collaboration with stakeholders along our main rivers and coastlines, by doing beach or city cleaning, campaigns and school education, free conferences, national sensibilization campaigns (medias, internet, TV), awareness-raising workshops, educational video games (Verschoor et al., 2016). It is important to sensitize the stakeholders to push them to develop a circular industry that uses less plastic (Boucher & Friot, 2017). Rising awareness is possible and crucial at each level of the society. However, the industrial part in charge of safety and cleanliness is often less aware about microplastic pollution but it's nevertheless an important source of microplastic in wastewater and later in oceans. It is why it is decisive today to raise awareness at each level and to continue in an integrated and interdisciplinary way to combat plastic and microplastic pollution (GESAMP, 2016; IPCC, 2014).

6. Conclusion

High rates of microplastic in the ocean has clearly been shown even if the quantification is not yet standardised. The various sources of marine microplastic begin to be well known, even if it is crucial to continue and improve investigation about secondary sources. Microplastic is consequently bioavailable and ubiquitous for zooplankton and causes their ingestion. The uptake is favoured by few factors such as size, shape and concentration of microplastics and their time exposure to these pollutants. This has some direct and indirect effects on zooplankton health systems. Direct impacts are quite well known but indirect impacts induced by the sorption and desorption properties of microplastics and the presence of POPs, PAHs and additives are less clearly defined and more difficult to study. Transfer of plastic particles is studied in more detail but numerous knowledge and technics gaps are still to be overcome to better understand the phenomenon. This would allow the analysis to be extended to large predators at the top of the food web. It is now essential for future research to standardise: firstly, the protocol of quantification of microplastics in ocean, the method to encounter the ingestion rate at real ocean microplastic concentration and secondly time going into the impact’s investigation in depth to assess the transfer of microplastic, POPs, PAHs and additives along the trophic chain. Because all this was demonstrated and because we now begin to know the negative effects on living beings it is crucial to continue research to better understand but also to use all the available instruments to develop plan of management to reduce the intake of microplastics in the ocean and their impact in the trophic chain.
References


