Food of the Future: A Literature Review on The Negative Effects of Nurdles on our Ecosystem

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Nurdle Soup

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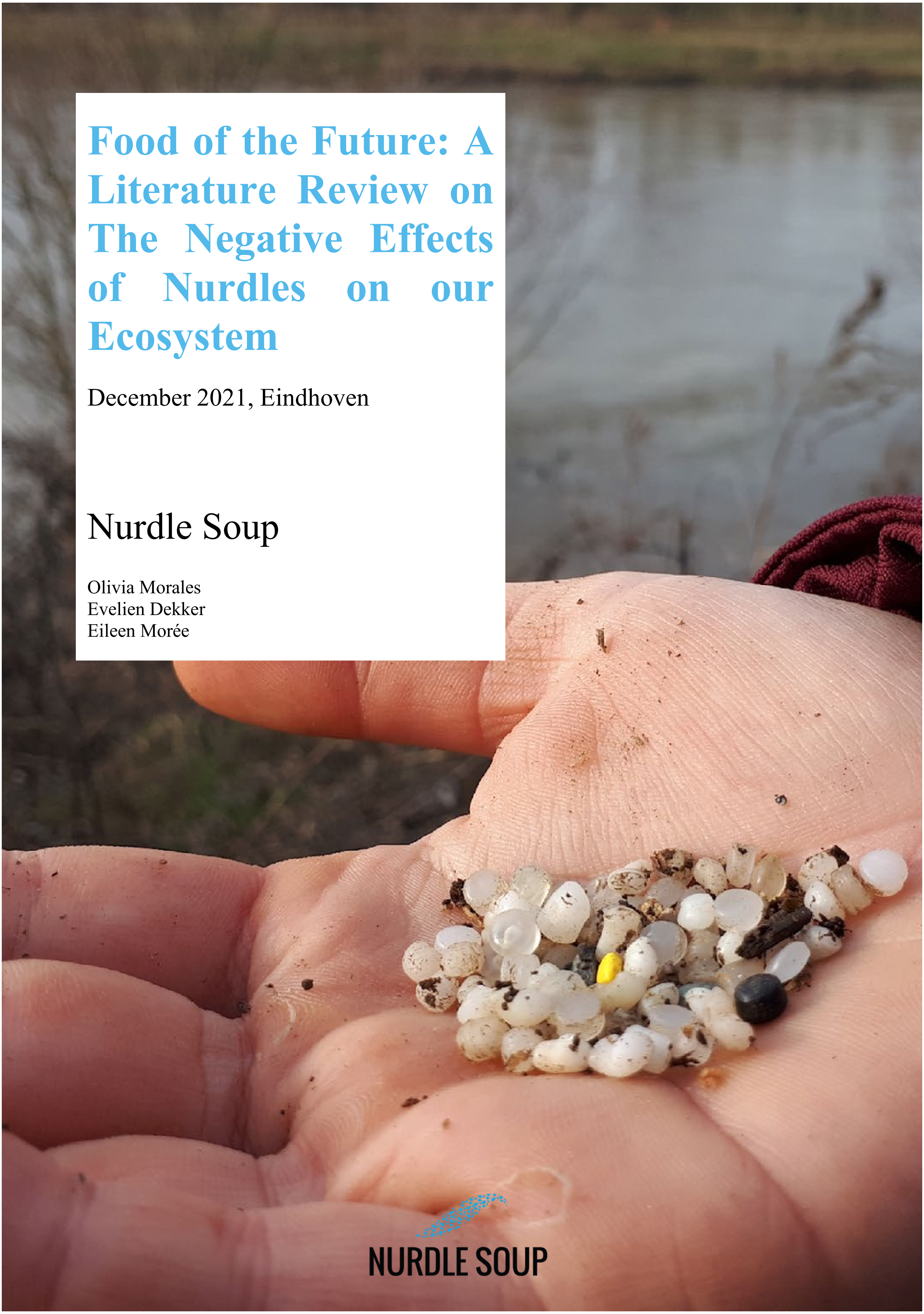

EXECUTIVE SUMMARY

This report provides an overview of the impact of nurdles in the environment. This has the purpose of getting acquainted with nurdles and some of the reasons behind the creation of the Nurdle Soup team.

A literature review study was conducted to map the possible ways that nurdles can impact the environment, both positively and negatively. However, literature concerning the impact of nurdles is still very limited, in comparison to general plastic pollution. Therefore, data from microplastics was extrapolated to complement the study due to the nature of nurdles. In this way, the reader can find certain facts or cases that can be applied to any type of microplastic, not only nurdles.

The research draws attention to the physical properties of nurdles. Characteristics like size and colour, that are given during the production stages, are needed to identify nurdles in the environment. Furthermore, this review elaborates on an important property, density, which can help to identify the type of nurdle. Although only two kinds of plastic are able to float (i.e. PE and PP), these two have the major share of plastics produced.

Both the physical properties and the chemical properties of nurdles are discussed, to evaluate how they will interact in the environment, particularly the aquatic environment. Due to their high surface area and the chemicals plastics are made of (additives) nurdles can absorb the chemicals present in water. Once a saturation level is reached, these chemicals are released into the environment. The processes are better known as sorption and leaching, which can be observed as a cycle that repeats continuously. The problem is further aggravated if it is considered that nurdles can easily transport chemicals, even dangerous ones, around the world.

Further impact is caused by the population with bacteria, such as chemicals that are moved around the world. The transportation of alien species can cause an ecological damage or the pollution of water with unknown species (e.g. bacteria)

Last, nurdles can be mistaken for food and be consumed by fish and other aquatic species. This causes severe damages for aquatic species and is the cause of bioaccumulation of dangerous chemicals, which can eventually affect humans through the consumption of these species.

NURDLE SOUP

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1. INTRODUCTION

'Nurdle' is the name identifying a small plastic pellet used for manufacturing plastic items. They are cylindrical or tear-shaped, and their diameter is generally smaller than 5 mm. Nurdles are released in the environment easily because of their small size and thoughtless management by several parties (Ellison, 2007). Moreover, due to their physical and chemical characteristics, the pellets present a severe danger to marine life. Research implies that nurdles can be poisonous as researchers have found birds that died of ingesting contaminated pellets. However, the depth of the impact is yet unknown to scientists (Ellison, 2007).

The following sections elaborate on the known impact of nurdles in the environment. It must be considered that as their production and consumption increase, the damage to the environment does too. Therefore, it is necessary to ensure their correct management.

2. NURDLE PRODUCTION

Plastic products are made from nurdles or pellets, which are defined as a small mass of preformed moulding material used as a feedstock in moulding and extrusion operations.

The production of pellets starts from the distillation of heavy crude oil, which separates the lighter groups called naphtha. The naphtha fraction is then cracked, which means that it is heated up to split it into smaller hydrocarbon molecules (e.g., ethylene, propylene). Once these monomer chains are obtained, they are linked to make polymers. This polymerization step is what determines the physical and chemical properties of the plastic. In addition to the polymerization process, chemicals can be added to improve or modify the properties of the plastics. These chemicals are known as additives and they are necessary to stabilize the plastics. However, these additives may have toxic effects (Andrady & Rajapakse, 2016). A list of common additives is presented in Table 1 (Andrady & Rajapakse, 2016).

The pellets obtained can have a variety of colours, which can be given at a pre- production stage or during remanufacturing. Then, the pellets are given the desired shape in converts.

Additive type	Example	Effect
Flame retardants	Polybrominated diphenyl ethers	Added to plastics like PVC, (can leach from food packaging into food and are suspected to be endocrine disruptors)
Plasticizers	Phthalates Di-2-ethylexyl phthalate (DEHP)	Soften the polymer making it more flexible and extensible
Process additive	Bisphenol A	Often used in food packaging (Endocrine disruptor)
Pigments	Toxic metals Chromium	To impart the desired colour to the product
Fillers	Clays, silica, glass, chalk, talc, asbestos, alumina, rutile, carbon black, carbon nanotubes	Reinforcement or reduction of cost
UV stabilizers	Hindered amine light stabilizers, benzophenone light-absorbing compounds	To control degradation of plastic on routine exposure to solar radiation
Thermal stabilizers	Dialkyl maleates or laureates and dialkyl mercaptides of tin in PVC formulations to retard HCl evolution during processing	To control degradation during processing

Table 1. List of additives commonly used in plastic production.

Plastic can be classified in two main groups, Thermoplastics and Thermosets, as seen in Table 2. Nurdles belong to Thermoplastics because they are moulded through heat.

Besides these two groups, the Society of the Plastics Industry (SPI) established a classification system in 1988 to allow consumers and recyclers to identify different types of plastic. Manufacturers place an SPI code, or number, on each plastic product, usually moulded into the bottom. This code distinguishes seven types of commonly used plastics:

Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Polyvinyl

Chloride (PVC), Low- Density Polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS) (Ryedale District Council, 2012), and "others", including Polycarbonate (PC), Polyurethane (PU), acryl, polyamide, bioplastics and many combinations of plastic that do not fit in one of the other classifications (Plastic Soup Foundation, n.d.).

The most produced plastics are Polyethene (PE), with a market share of 27-33% (Biron, 2012).

TYPE OF PLASTIC	EXAMPLE OF APPLICATION[1]	MARKETSHARE (%)[2]
Thermoplastics		**81**
Polyethylene (PE)	Packaging, bags, toys, milk cartons	27-33
Polypropylene (PP)	Car components, packaging textiles	18-19
Polyvinyl chloride (PVC)	Floors, window frames, pipes	11-12
Polyethylene Terephthalate (PET)	Bottles, pots, textiles (polyester)	7-9
Polystyrene (PS)	Frames for glasses, single-use cups, food packaging	6-8
Polyamide (PA)	Textile (nylon, Kevlar), electronics	1
Thermoplastic elastomer (TPE)	Rubber, silicone, elastics	1
Other thermoplastics		3-4
Thermosets		**14**
Polyurethane (PUR)	Isolation, mattresses, coating	5-7
Amino resins (UF, MF[c])	Textile, isolation, laminate flooring	2-5
Unsaturated thermosets	Fiberglass-reinforced polyester (tarpaulin), cord layer for tires	2-3
Phenolic resins	Coatings, billiard balls	1
Other thermosets		1
Other plastics (mainly composites)		**6**

Table 2. Share of different types of plastics in industrialized countries (CPB, 2017).

[1] *Plastics Europe (2016; 2017a), Singh et al. (2016). [b]Source: Table 2.3 in Biron (2012). Data most likely concerns 2010*

[2] *UF stands for urea formaldehyde and MF stands for melamine formaldehyde.*

3. PHYSICAL AND MECHANICAL PROPERTIES

Nurdles present a threat to the environment; they remain in the environment for a long period of time, enhancing their negative impact on many different levels. This resiliency is caused by the mechanical and physical properties given to the plastics. Therefore, it is important to know these properties to evaluate and compare how they interact and disrupt the environment (Fotopoulou & Karapanagioti, 2012). Two properties of interest are discussed in detail below.

3.1 DENSITY

Accidental spills and mismanagement cause great amounts of nurdles to end up in the aquatic environment. Their low density facilitates their aquatic transport and as result they are found worldwide.

The floating property of pellets is of high importance. For instance, debris traps fail to catch nurdles because of this property. Floating is the result of their density. This property is measured in respect to water and temperature. At a temperature of 0 degrees Celsius, the density of water is 0,99982 g/cm³. At 25 degrees the density is 0,99713 g/cm³ (ThermExcel, 2003). According to Rijksoverheid (2017), the average water temperature in the Netherlands between 2006-2015 was 14 degrees.

The density of the most commonly produced plastics in industrialized countries is presented in Table 3. As it can be observed the density of PE and PP is lower than the density of water. Therefore, they are the easiest type of plastic to spread in the environment due to their floating property. PE and PP also are the most common plastic produced, around 45-52% with PE around 27-33% and PP around 18-19%.

Moreover, after some time in the ocean, floating plastic debris may become sufficiently fouled with biological growth and can sink (Ye & Andrady, 1991). Therefore, it is possible to find nurdles throughout the water column. However, they are largely concentrated near the surface and on the ocean floor (Engler, 2012). Finally, their density can also be altered by the degradation, fragmentation, and leaching of additives (Avio, Gorbi, & Regoli, 2017).

TYPE OF PLASTIC[3]	DENSITY AT 20 °C IN g/cm³	FLOATS IN WATER[4]	SOURCE
PE	0.94	Yes	(WordPress, n.d.)
PP	0.90	Yes	(WordPress, n.d.)
PVC	1.30	No	(WordPress, n.d.)
PET	1.38	No	(Wikipedia, n.d.A)
PS	1.04	No	(WordPress, n.d.)
PA	1.15	No	(Wikipedia, n.d.B)
TPE	0.91 - 1.3	Some, but neglectable	(BPF, n.d.)

Table 3. The main plastics and their densities[5].

[3] There are more types of plastic than only these types. However, these are the most common in industrialized countries.
[4] The floating capacity is considered only for the pellets (appr. 6 mm in diameter). Larger plastics in specific forms like PVC pipes can float on water due to their shape, even though their density is higher than water.
[5] The influence of additives is not considered in the density.

3.2 SURFACE PROPERTIES

The surface properties such as surface area, pore volume, topography, and functional groups determine the sorption of pollutants; therefore, they are of great interest.

Virgin plastic pellets have a melting point of 177.8°C. This type of plastic is very resilient to corrosion, impact, and flame. Generally speaking, virgin pellets have a smooth and homogenous surface (Pozo et al., 2020). However, the surface of the pellets is affected during the period of exposure to the environment and thus it is being modified constantly. Once these modifications occur, their physical and chemical interaction with the environment changes, e.g., their acid-base behaviour. Limited research has been conducted on the area and it is relatively unknown how to determine the time that nurdles have been in the environment based only on their physical status. This lack of information highlights the importance of avoiding the leakage of nurdles, and plastic in general, into the environment.

4. NURDLES AS VECTORS OF POLLUTION

Plastics are considered inert materials. They have a large molecular size, which does not allow interaction with the cell membrane. However, nurdles can act as vectors of contaminants due to their physical and mechanical properties.

Plastic debris present in the marine environment carries chemicals of small molecular size (e.g., additives). These chemicals can penetrate the cells, interact with molecules, and may disrupt the endocrine system of the marine biota. Such chemicals are categorized into two groups:

1. Hydrophobic chemicals: are absorbed from surrounding seawater due to affinity with the hydrophobic surface of the plastics (Teuten et al., 2009).

2. Additives, monomers and oligomers of the component molecules of the plastics. (Teuten et al., 2009). While pure plastic resins are nontoxic (and cannot be digested or absorbed by humans) the additives that leach out from the plastic products can present a toxicity concern (Andrady & Rajapakse, 2016).

The chemicals interact with the environment through two mechanisms, namely sorption and leaching. Below, both mechanisms are elaborated.

4.1 SORPTION MECHANISM OF POLLUTANTS AND THEIR TRANSPORT

The environmental burden that the industry causes is well known. Contaminants from the industries enter the marine environment through wastewater disposal, water runoff, wind, intentional or accidental disposal, and extreme weather events (Baeman et al., 2016). However, their damage can be increased due to the plastics present in the environment. They can serve as carriers of organic contaminants to the environment.

As explained before, once plastics are exposed to the conditions of the environment, such as heat, radiation, mechanical forces, and even biological agents, their properties are altered. These altered plastics, unlike virgin plastic, sorb chemicals such as metals or hydrophobic organic compounds in larger amounts. The degree of weathering has an effect in the sorption and is dependent on the type of POPs (Persistent Organic Pollutants), but in general the older the pellets are, the higher the concentration of contaminants (Pozo et al., 2020). Factors like the large surface area, affinity to hydrophobic compounds enhance the sorption capacity (Fotopoulou & Karapanagioti, 2012). Plastic debris may, therefore, pose a greater toxic threat to the food chain the longer it remains at sea (Science for Environment Policy, 2013; Engler, 2012). This then causes a chain effect affecting the natural biota. It was found that algae growth is affected by the presence of microplastics that had absorbed pharmaceutical compounds (Pozo et al., 2020).

Hydrophobic organic chemicals have greater affinity with plastics (e.g., polyethylene, polypropylene, PVC) compared to that of the natural sediments. They are absorbed at concentrations scaled from ng to mg (Teuten et al. 2007). Moreover, it has been found that they can accumulate in plastic debris at

concentrations up to six orders of magnitude greater than their accumulation in the surrounding water.

Persistent Organic Pollutants are of great concern due to the resilience to degradation and facility to bioaccumulate. Some of these compounds were added during manufacturing stages, while others are adsorbed from the surrounding seawater (Baeman et al., 2016).

Among them are the Polybrominated diphenyl ethers, which are organic bromine compounds used as flame retardants. Polychlorinated biphenyls are organochlorine compounds generally used as dielectric or cooling fluids. Organochlorine pesticides such as DDT, were developed as insecticides. Due to their well-known environmental impact, many have been banned for more than a decade. However, they are still found in plastic pellets. Hexachlorobenzene (HCB), is used in formulations for pesticides for fungal containment. This type can be released to the atmosphere from chlorine pesticides that have been incinerated, from coal, from fuel or even biomass. It has been banned since the '80s. Penta-chlorobenzene is a chlorinated aromatic hydrocarbon used in PCB products, also as fungicide, flame retardant. Table 4 presents the maximum concentration levels of these POPs found in plastic pellets (Pozo et al., 2020).

Type of POPs	Maximum sorption
PBDEs	133 ng/g-pellet
PCBs	<10 ng/g-pellet
DDTs	<7 ng/g-pellet
HCB	<4 ng/g-pellet
PeCB	<3 ng/g-pellet

Table 4. Maximum sorption of POPs in average nurdles.

A study was conducted by Rochman et al. (2013) on the sorption of polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs), to the five most common types of mass-produced plastic: polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), and polypropylene (PP). They found that the 'rubberlike' plastics, such as HDPE, LDPE and PP, consistently attracted concentrations of pollutants ten times greater than the 'glass-like' polyvinyl chloride (PVC) and polyethylene terephthalate (PET)

(Science for Environment Policy, 2013). These data imply that products made from HDPE, LDPE, and PP pose a greater risk than products made from PET and PVC of concentrating these hazardous chemicals onto fragmented plastic debris ingested by marine animals (Rochman et al., 2013).

However, in the case of other types of pollutants the authors also caution that the results they found may not extend to those and advise that further research is needed to establish how other pollutants interact with different plastic types (Science for Environment Policy, 2013).

Metals such as aluminium, iron, copper, cadmium and nickel can also be adsorbed by plastics. Table 5 presents the levels of concentration found in these metals in pellets. Like with organic compounds, the concentration of metals increases in aged pellets due to increase in polarity. Other environmental conditions e.g., change of pH, can also change the adsorption capacity of metals in plastics. (Avio, Gorbi, & Regoli, 2017).

Concentration	Metal
300 µg/g	for Al, Fe, Cu, Pb and Zn
800 µg/g	for Cd, Cr, Co, Ni

Table 5. Concentration of metals in nurdles

4.2 LEACHING

Leaching of pollutants is the second way nurdles can act as vectors of pollutants (Fotopoulou & Karapanagioti, 2012). Besides boosting the degradation of plastic, additives can desorb from it. How fast this desorption happens depends on pore size, typology, and environmental conditions (Avio et al., 2017). The additives added during the plastic production, e.g., polybrominated diphenyl ethers, nonylphenol or triclosan, modify the properties of the pure polymers to increase pliability, resist ultraviolet radiation, reduce flammability or degradation, or impart other preferred physical characteristics to the finished product (Andrady & Neal, 2009; Lambert, Sinclair & Boxall, 2014). They can increase the amount of dissolved organic Carbon (DOC) in water. It has been calculated that around 23600 tonnes of DOC are released in the marine environment every year (Engler, 2012).

The additives can remain in the environment for a long time, particularly in the body of the aquatic species, a phenomenon known as bioaccumulation. However, the chronic effect that additives have on aquatic species is not yet well known. Additives like phthalates, bisphenol A, alkylphenols, or polybrominated diethyl ethers can act as endocrine-disrupting chemicals that affect the synthesis of hormones. Because of this, some chemicals like bisphenols have been banned (Avio et al., 2017; Fotopoulou & Karapanagioti, 2012).

The presence of microplastics in the environment can also cause the degradation of dissolved organic matter to particulate organic matter, disturbing the carbon cycle in marine environments. Among the most dangerous possibilities is that nurdles can transport heavy metals (Engler 2012).

Due to the resilient nature of plastic debris, it can remain for long periods in the aquatic environment. This plastic may turn into a source of chemicals to the aquatic environment if the ingredients that were used when the plastic was made (e.g., monomers and additives) leach into the surrounding waters. Plastic may also become a sink for chemicals in which chemicals from the surrounding aquatic environment can accumulate (e.g., persistent, bio-accumulative, and toxic (PBT) contaminants) (Engler 2012).

On the other side, the sorption behaviour of microplastics is not well defined, more research needs to be conducted. It is considered that ageing nurdles can present the same behaviour as secondary microplastics. Secondary microplastics have different roughness, oxygen functions and surface area that can significantly enhance the absorption of pollutants. With time, the degradation of plastics can also cause secondary reactions such as hydrolysis. Hydrolysis in nurdles can increase the adsorption of hydrophobic chemicals, e.g., polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and other benzene-ring derivatives. Moreover, exposure of the nurdles to UV causes the accumulation of oxygenated moieties[6].

It can be hard to determine whether a compound has been in the plastic since manufacturing or was adsorbed from the environment. Polycyclic aromatic hydrocarbons (PAHs) can be formed during polystyrene production or can be adsorbed from the environment.

Due to their large molecular size, polymers are usually considered to be biochemically inert, i.e., do not interact biochemically, and therefore do not pose a threat to the environment. However, unreacted residual monomers or small oligomers can be found in the plastic material since polymerization reactions are seldom complete. The concentration of these residual monomers may vary between few parts per million to several percent depending on the polymer type and manufacturing process. Some of the monomers used are considered harmful: BPA disrupts endocrine function, whereas styrene and vinyl chloride monomers have both shown to be carcinogenic and mutagenic. In contrast, some plastic monomers, such as ethylene and propylene, are not considered hazardous.

In a study by Lithner, Larsson & Dave (2011) assessing the harmfulness of plastic polymers based on their chemical composition, 29% of the 55 polymer types studied were partly or completely made of monomers that are classified either as carcinogenic, mutagenic[7], or toxic for reproduction. Poly- urethanes (PUR), polyacrylonitriles (PAN) and polyvinyl chlorides (PVC) were considered as the most hazardous polymer types according to their monomer composition, whereas poly- propylene (PP), ethylene-vinyl acetate (EVA), polyvinyl acetate (PVAc) and polyethylene (PE) were evaluated to be the least hazardous. This ranking does, however, only consider the monomers and

[6] Moieties: branches extending from the backbone of a hydrocarbon molecule

[7] Inducing or capable of inducing genetic mutation

does not pay attention to the numerous additives used in plastic production.

Despite their harmfulness, in many cases the most hazardous substances in plastics are not the monomers but other compounds, such as solvents, initiators, catalysts and other polymerisation additives. Some solvents may be toxic and flammable, and they can be hard to evaporate or precipitate from the polymer when manufacturing. Toxic solvents to aquatic life include for example methanol, cyclo- hexane, and heptane. The most hazardous initiators include potassium persulfate and benzoyl peroxide, which cause respiratory problems and skin irritation. Catalysts are usually based on different metals, and they include for example tributyltin, zinc oxide and copper chloride, which are considered very toxic to aquatic life.

Several thousand different additives are used in the plastic production. Brominated flame retardants, phthalates and lead compounds are used as heat stabilizers. These are considered the most hazardous additive types. Some of the brominated flame retardants, such as PBDEs, structurally resemble polychlorinated bis- phenols (PCBs) which are well-known environmental contaminants accumulating in the fat tissues of aquatic animals. They can cause neurotoxic effects and alter the function of thyroid hormone. Phthalates[8] are estrogenic compounds that can disrupt endocrine function and reproductive systems of animals. Studies have shown that especially lower molecular weight phthalate plasticizers are acutely and chronically toxic to a variety of aquatic microorganisms, algae, invertebrates, and fish.

4.3 VECTORS OF ALIEN SPECIES

Around the world different organisms have been observed being transported in floating objects, these species have been named "invasive species" (Avio et al., 2017).

In the same way nurdles can become fouled with algae creating a biofilm in which contaminants can be bioaccumulated and transported (Avio et al., 2017). The layer between the plastic surface and the bacteria is called plastisphere and provides protection for the bacteria against UV irradiance, making them more resilient. Moreover, these bacteria can travel long distances. On some beaches around the world, for example, dangerous bacteria such as E. coli[9] or Vibrio have been detected. The colonization process is also enhanced when present in environments with low nutrients (Rodrigues, Oliver, McCarron, & Quilliam, 2019). This fouling organisms such as algae, biofilms, and invertebrates that have colonized the plastic particles, causes the debris to sink to the seafloor and mix with the bottom sediment (Derraik, 2002; Barnes et al., 2009; Cole et al., 2011).

5. IMPACT ON MARINE BIOTA

Besides transportation of pollutants, it is also important to acknowledge the effect on the marine biota. The presence of microplastics has been demonstrated by the presence of charged polystyrene beads. They are ingested affecting their physiology. Among the effects known are the negative impact on the feeding rate and fertility. It has been reported that animals that feed directly off them, such as mussels, lost weight, which can lead to diseases. Besides, under high exposures higher mortality rates were observed.

The long-term impact is also a great concern. Ingested plastic bioaccumulates over time, see Figure 1. This means that both additives and other components of plastic are available through the food chain. The impact of the substances is determined by the pH level, surfactants, and hydrophobicity in the gut environment and the residence time of the plastic in the organism. For example, high levels of fat in the gut enhances the availability of additives such as

[8] Also known as plasticisers, are esters of phthalic anhydride (i.e. organic compounds with formula: -$C_6H_4(CO)_2O$)

[9] This bacterium is found normally in the intestines of livestock. When it gets in contact with humans it can cause diarrhoea, urinary tract infections, respiratory illness and pneumonia

phthalates (Guart, Bono-Blay, Borrell, & Lacorte, 2011; Yamashita et al., 2018). As we move along the food chain the accumulation of toxins increases (Science for Environment Policy, 2013).

The effect also varies from the type of plastic. Plasticized polyvinyl chloride, for example, causes inflammation.

Furthermore, polyethylene increases the susceptibility of the enzymes involved in neurotransmission processes. Moreover, virgin plastics cause alterations in the immune system, destabilize the lysosome membrane and damage the DNA (Avio et al., 2017).

Besides the severe impact on the health of the marine biota. Human bioaccumulation poses a high risk to human health. Added to this is the biomagnification effect, which is defined as the movement of chemicals across the food web. This effect is detrimental, i.e., the danger increases as we move across the food chain, being of great danger to the consumers in last positions (e.g. humans) (Ali & Khan, 2018; Cui et al., 2015; Winter & Streit, 1992)

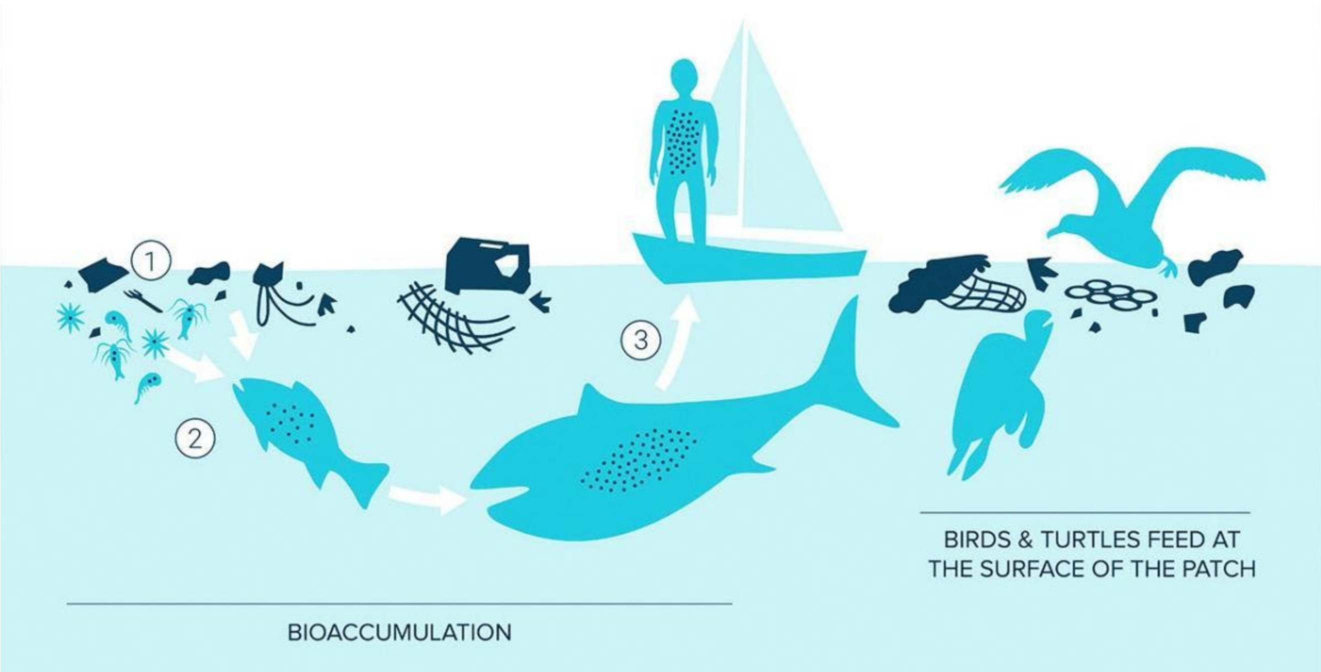

Figure 1. Bioaccumulation of plastics (The Ocean Cleanup, 2020).

6. CONCLUSION

Nurdle is the name given to the small pellets of thermoplastics used to produce bigger plastic items. They are key for the plastic industry. However, its mismanagement has caused large amounts of spills in the environment every year.

Their small size and cheap price have caused the lack of care and attention for this growing issue. Moreover, due to their physical properties, particularly their density and size, it is difficult to design a solution to capture the nurdles. As a consequence, their presence in the environment increases every day.

On the other hand, the impact of nurdles on the environment is not fully known. Therefore, this report focused on finding the way these nurdles impact the environment, particularly aquatic bodies.

It was found the different ways that nurdles can act as vectors of pollution. Namely sorption and leaching. These mechanisms nurture each other, aggravating the problem. They are responsible for the transportation of dangerous chemicals and alien species around the world such as organochlorine pesticides like DDT. This can potentially lead to the pollution of water that is also used for human consumption.

Besides being vectors of pollutants, animals ingest them. Ingesting a nurdle that contains dangerous chemicals leads to the bioaccumulation of them, as they cannot be digested. The problem is magnified through the food chain, affecting both animals and humans. Thus, this negatively influences the health of both animals and human beings.

The degree of the effect of nurdles and the scale of their spillage is not known. But the presence of nurdles has been confirmed all around the world. The marine environment and the food chain within it are very complex systems. In this way, the actual wide scale effects of plastics entering this environmental system or even the system of a human body is difficult to predict. Therefore, more research is needed to answer these questions and to come up with measures to decrease and prevent the spillages from happening in the first place.

Despite many facts being found it is important to extend the area of research. It is recommended to complement the investigation and tailored to the region of interest, the Netherlands.

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