KNOWLEDGE BOOKLET

Plastic and Health

2024

Plastic and Health: A Knowledge Handbook

Chapter I. Concepts and the History of the Plastics Industry

1. Concept

Plastic (also called synthetic resin or polymer) refers to macromolecular compounds containing repeating units along the length of the chain; they can be reshaped and are formed under heat and pressure. Plastics are typically combined with other chemicals to produce items ranging from everyday household goods to industrial products.

Plastic is not a single, uniform material but rather encompasses many types with different properties and distinct applications. Plastics are organic compounds derived either from fossil feedstocks such as petroleum, natural gas and coal, or from biological feedstocks—most typically the starch of corn, potato and cassava.

Figure. Bottled water—a common application of plastic materials.

2. The history of plastics

2.1. A brief history of the global plastics industry

1870–1900. One of the important milestones for plastics came in 1856, when Alexander Parkes was granted a patent for the first artificial bio-based plastic, called Parkesine, made from cellulose nitrate. While searching for a substitute for ivory, John Hyatt, an American chemist, developed Parkesine into a stable and more highly applicable compound named "celluloid." Celluloid soon became a favored material thanks to its low cost and ease of processing, and was used very widely in industries manufacturing toys and personal items.

Figure. Alexander Parkes (1813–1890)—father of the first plastic.

1900–1930. An important plastic material brought into industrial production was PolyVinyl Chloride (PVC). As early as 1872, PVC had been synthesized from its main feedstock, vinyl chloride. However, PVC's applications at the time were very limited owing to its poor stability, high rigidity and difficulty of processing. It was only in 1926, when Dr. Waldo Semon invented the plasticization method, that PVC began to be brought into industrial production.

1930–1990. The early 1930s were a pivotal period for the development of the modern plastics industry, when manufacturers found methods to produce plastic feedstock from petroleum at industrial scale. During the period 1950–1960, after the end of the Second World War, plastic manufacturers began seeking a new market for their products: the consumer market. Plastic materials that had previously served mainly the war effort were gradually transformed into everyday consumer goods. During the 1960s, worldwide plastic production grew by 400%, changing people's consumption habits. Factors such as low cost, mass production and single use led people to consume ever more plastic products, especially packaging and wrapping products.

1990–present. The plastics industry is now growing more slowly and shows signs of saturation. The per-capita plastic consumption index of regions such as NAFTA, the EU and Japan is already 200–300% higher than the world average. In the coming years, the growth rate of the global plastics industry is forecast at 3–4%, with growth driven by regions where per-capita plastic consumption is rising quickly, such as China and Southeast Asia (including Vietnam). New technologies, however, continue to be invented, helping to make plastic the material of the future—prime examples being 3D printing and Nano technology.

Note. The plastics industry has a history of more than 100 years worldwide and has step by step become a common material serving human daily needs. China and Southeast Asia (including Vietnam) are the drivers of the industry's development.

2.2. A brief history of Vietnam's plastics industry

The first milestone of Vietnam's plastics industry was the construction of the country's first PVC production line, built with Chinese support at the Việt Trì Chemical Plant in 1959. During this period, PVC feedstock was used mainly to serve the national defense industry. The Việt Trì Chemical Plant continued producing PVC until 1976, when the PVC line had to cease operating due to obsolete technology and severe deterioration.

Before the 1990s. Vietnam's plastics industry had not yet developed; production was mainly assembly, and most plastic products in this period depended on imports. The plastic products manufactured during this period were almost all simple in design and limited in form and style.

The period 1990–1999. A period of rapid development for Vietnam's plastics industry under the state's Đổi Mới (renovation) policy. Domestic plastic-feedstock production capacity also improved considerably in this period with the appearance of a large petrochemical joint venture, TPC Vina (a joint venture between the Thai plastics and chemicals company TPC, the Vietnam Chemicals Group Vinachem, and the Vietnam Plastics Joint Stock Company). During this period, Vietnam's plastic feedstock production remained concentrated mainly on PVC.

The period 2000–2007. A period in which the plastics industry developed rapidly, with average output growth of about 13.5%. Plastic-feedstock output also improved considerably with the appearance of a second joint venture, Phú Mỹ Plastics and Chemicals (a joint venture between Petronas Malaysia and Bà Rịa–Vũng Tàu province) in 2002. During this period, the industry's products also became more diverse in style, and quality improved considerably.

The period 2007–present. The plastics industry has continued to develop strongly, especially after Vietnam joined the World Trade Organization (WTO). In 2017, Vietnam's plastics industry consumed about 5.9 million tonnes of virgin plastic feedstock, equivalent to a per-capita plastic consumption rate of 63 kg/person/year. This rate for Vietnam in 1990 was only 3.8 kg/person/year; thus, over the period from 1990 to 2017, Vietnam's per-capita plastic consumption rate grew by an average of 10.6% per year. (Source: Hotpot report, IUCN.)

Note. Vietnam's plastics industry developed later than the rest of the world and still has considerable room for future growth.

2.3. The plastics industry value chain

2.3.1. Overview of the plastics industry value chain

The value chain of the plastics industry, from fossil feedstock to the final plastic products, comprises two segments: upstream and downstream.

The upstream segment of the plastics value chain. Crude oil is the feedstock that yields the most diverse output product mix, while natural gas is the feedstock with an advantage in producing Polyethylene (PE). Each type of input feedstock yields a different output composition.

The downstream segment of the plastics value chain. The downstream segment of the plastics industry is the process in which plastic feedstock is used by manufacturers to form plastic products.

Figure 1. The plastics industry value chain (downstream segment).

The downstream segment of the plastics industry uses various plastic pellets as input feedstock; through physical transformation and shaping, this feedstock is turned into plastic products. The downstream segment is divided into four main areas corresponding to four types of output product: (i) packaging plastics, (ii) construction plastics, (iii) consumer (household) plastics, and (iv) engineering plastics. Each sub-area of the downstream segment has different input and output characteristics (see Table 1).

Area	Packaging plastics	Construction plastics	Consumer (household) plastics	Engineering plastics
Plastic feedstock	PE (HDPE, LDPE), PP and PET	PVC, PE (HDPE)	PP, PS, ABS	PVC, PP, PU
Production technology	Extrusion blow molding	Extrusion molding	Injection molding	Injection molding
Typical products	Thin-film packaging, nylon bags, PET plastic bottles	Plastic pipes, ceiling panels, plastic walls	Household appliance products	Various components and accessories

Table 1. Main characteristics of each area in the plastics industry value chain (downstream segment).

Packaging. Packaging plastic products accounted for as much as 30% of the total output of the global plastics industry in 2017, equivalent to about 115 million tonnes. Packaging plastic products include nylon bags, multilayer film packaging, plastic bottles and the like, serving mainly the food and beverage processing industries and retail and supermarket chains.

Construction. The volume of construction plastic products in 2017 reached about 64 million tonnes, accounting for about 17% of the total output volume of the global plastics industry. Construction plastic products include water pipes, plastic doors (profile bars), floor panels, ceiling panels and the like.

Automotive and electrical–electronics industries. Engineering plastic products serving the automotive and electronics industries account for 17% and 5%, respectively, of the total output of the plastics industry.

Household plastic products. Household plastic products include plastic boxes, plastic cups, kitchen products and the like.

Demand for the output of the two areas—packaging plastics and consumer plastics—both depend on population size, income and household spending. The output of the packaging area consists of plastic films and bottles used to package the products of other industries, such as beverage and food processing; while the output of the consumer plastics area consists of products serving household needs, such as plastic furniture, kitchen utensils and plastic boxes. Therefore, growth in population size together with rising incomes will drive up demand for packaging and consumer plastic products.

Note. As the population, income and spending of the Vietnamese people rise, demand for the output of the two areas—packaging plastics and consumer plastics—will increase in the coming period.

2.3.2. Overview of the production technologies used in the plastics industry

Three production technologies are commonly used in plastics manufacturing today:

Blow molding (Extrusion Blow Molding). Blow molding is a common technology used to produce nylon bags, multilayer film packaging, and plastic bottles and jars for packaging the products of the food and beverage processing industry, or for direct use in retail and supermarket systems.

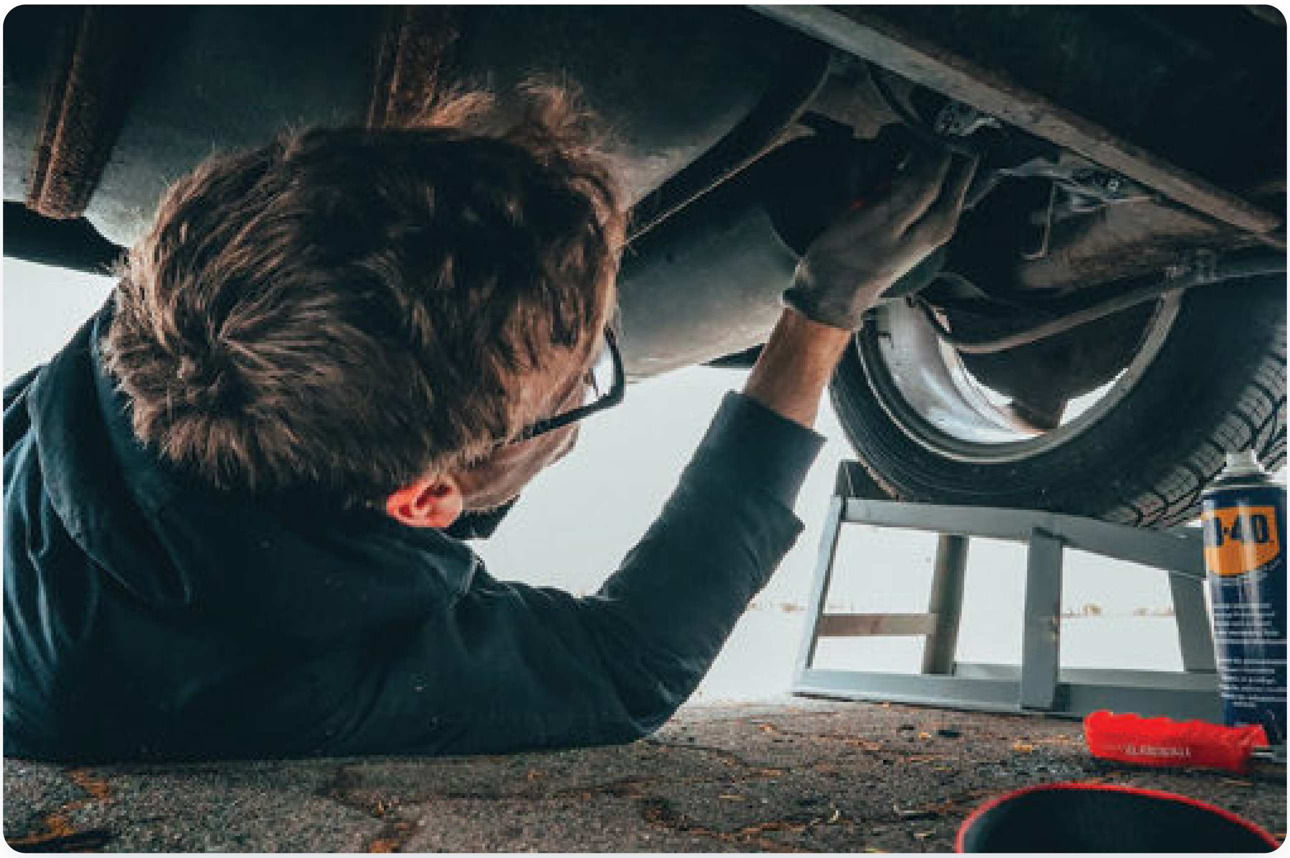
Injection molding. Injection molding is a technology commonly used to produce most plastic products from molds in large quantities. It is applied mainly to manufacture household plastic products such as containers and plastic boxes, as well as engineering plastic components serving the manufacturing and assembly industries.

Extrusion molding. Extrusion molding is used to produce construction plastic products such as plastic pipes and plastic-door profile bars, or various plastic films used in agriculture.

Figure. Diagrams illustrating the blow molding, injection molding and extrusion molding technologies.

Chapter II. Classification of Plastics

Plastics are classified according to many factors; in this handbook, however, we record only the three most common methods of classification: by the response of the polymer to temperature; by the resin identification code; and by the value of the plastic (recycling value).



1. Classification by the response of the polymer to temperature

Thermoplastics. A type of plastic that, when heated to its softening point, softens and flows, and hardens again when the temperature is lowered. Thermoplastics are usually synthesized by polymerization. Their mechanical properties are not high compared with thermosetting plastics. Thermoplastics can be recycled many times; examples include polyethylene (PE), polypropylene (PP), polystyrene (PS), polymethyl methacrylate (PMMA), polybutadiene (PB) and polyethylene terephthalate (PET).

Thermosetting plastics. A type of plastic material that, when heated to a certain temperature, changes both physical shape and chemical properties, forming a three-dimensional spatial structure and can no longer be re-melted. Thermosetting plastics therefore cannot be recycled. Some common thermosetting plastics are Epoxy, Vinyl Ester, Melamine and Polyurethane.

Elastomers. A type of plastic with elasticity like rubber.

2. Classification by resin identification code

On the underside of plastic bottles there is usually a triangular symbol enclosing an arbitrary number. This symbol is called the Resin Identification Code (RIC), issued by the American Society for Testing and Materials (ASTM). The numbers displayed within the triangle, from 1 to 7, are the code numbers describing the type of plastic that makes up a given plastic product. The seven types are PET (1), HDPE (2), PVC (3), LDPE (4), PP (5), PS (6) and Other plastics (7).

2.1. Polyethylene terephthalate plastic (PET/PETE)

PET or PETE is an important type of food packaging that can be formed into films or into bottles and jars. Because of its very high barrier properties, PET is used to make bottles and containers for purified water, carbonated soft drinks and the like.

Most soda bottles and mineral water bottles are plastic type 1. This type of plastic is generally safe; however, it should not be reused to hold drinking water or food. The reason is that its surface has many pores and is spongy, which can allow bacteria and odors to accumulate and is very hard to clean thoroughly. This plastic is considered a single-use plastic and is very easy to recycle.

When PET is heated to 200°C or cooled to -90°C, the chemical structure of the PET chain remains intact, and its gas/vapor barrier properties remain unchanged at temperatures around 100°C.

2.2. High-density polyethylene plastic (HDPE)

High-molecular-weight polyethylene (HDPE) is a thermoplastic made from petroleum; it is commonly used in manufacturing plastic bottles, corrosion-resistant pipes, waterproofing membranes and wood-plastic composites in the food industry. The best type of plastic for long-term food storage is high-density polyethylene (HDPE), designated by the symbol "2." HDPE is one of the most stable forms, and all plastic containers sold specifically for food storage are made from this material.

Most infant milk bottles, milk and fruit-juice bottles, and containers for detergents, shampoo, dishwashing liquid and shower gel are plastic type 2. Although opaque in color, this plastic is considered safe because bacteria have difficulty accumulating on its rather smooth surface. Plastic type 2 is also considered easy to recycle.

Properties. High mechanical strength, able to withstand tearing and impact forces, high abrasion resistance and high rigidity; inert to the food environment; better O_2 and CO_2 barrier than other plastics; transparent.

2.3. Low-density polyethylene plastic (LDPE)

LDPE is low-density polyethylene plastic. It is commonly used to make various types of packaging, grocery plastic bags, food wrapping paper and the like. This plastic is considered fairly safe and easy to recycle.

LDPE is found in: squeezable bottles; bread and frozen-food bags; dry-cleaning and shopping bags; clothing bags; furniture; and carpets.

Properties. Known for its high strength relative to density, with a mass density that can range from 0.93 to 0.97 g/cm^3; abrasion- and impact-resistant even at low temperatures; very good chemical resistance; low coefficient of friction, good electrical insulation, and high resistance to energy radiation.

2.4. Polyvinyl chloride plastic (PVC)

PVC products were previously (from the 1920s onward) used in very large quantities, but today they have been surpassed by PE products. At present, PVC is used mostly to sheathe electrical cables, make drainage pipes, raincoats, household plastic films and the like.

PVC contains vinyl chloride, commonly known as VCM, which carries a risk of causing cancer (discovered around the 1970s). PVC is often used to make label films for plastic bottles and containers, or as shrink film wrapping foods stored and circulated for a short time, such as raw meat and fresh produce. In addition, PVC is used to make many household items and various products in other industries.

Properties. Density: at 1.4 g/cm^3, PVC is denser than PE and PP, so a large amount of PVC feedstock is needed to obtain a film of the same area and thickness as PE and PP. Its vapor and water barrier is poorer than that of PE and PP. It is brittle and not as flexible as PE or PP. To make flexible PVC for packaging use, additives must be added; plasticized PVC will become hard and brittle again after a period of time. Although residual VCM has been controlled to below 1 ppm—the permitted safe level—in Europe PVC is still not used for food packaging, even though it is cheaper than other plastic packaging.

2.5. Polypropylene plastic (PP)

PP is a plastic made from polypropylene. Yogurt cups, drinking-water bottles, medicine bottles, syrup or ketchup and chili-sauce bottles, drinking straws and the like are all made from plastic type 5. This plastic is considered safe and very easy to recycle.

PP is used to make single-layer packaging to contain and preserve food that does not require strict oxidation protection. PP is also used to form fibers woven into sacks for holding large quantities of foodstuffs and cereals. PP is also produced as an outer coating layer for multilayer films to increase the gas and water-vapor barrier, provide high printability, allow easy tearing to open the packaging (thanks to a pre-formed tear notch) and give the packaging high gloss.

Properties. PP has high mechanical strength (tear- and tensile-resistant), is fairly rigid and not as flexible as PE, and does not stretch, so it can be made into fibers—though it tears easily when there is a cut or a small puncture. It is transparent with a high surface gloss, giving high printability and clear print. It withstands temperatures above 100°C; however, the sealing temperature of the body of PP packaging (140°C) is higher than that of PE—which can melt and damage the outer structural laminate—so PP is rarely used as the innermost layer. PP resists the permeation of O_2, water vapor, oils and other gases.

2.6. Polystyrene plastic (PS)

Polystyrene, also known as foam (xốp), is commonly used for cushioning, packaging and thermal insulation. Plastic type 6 is often also used to make plates, bowls for instant noodles, and containers for foods such as broth and soup, as well as disposable cups.

There is growing evidence that this plastic can release toxic chemicals, especially when it holds hot food. We should therefore avoid using type-6 plastics to hold food. Plastic type 6 is very difficult to recycle.

2.7. Other plastics

Type 7 essentially means "everything else." This category consists of products made from mixtures of plastics invented after 1987, including Polycarbonate (a hard, transparent plastic) and BPA, which is dangerous to human health.

Almost no household plastic items bear the number 7 label. This plastic is used mostly in industry, from telephone casings to computer housings. Label type 7 is also very difficult to recycle.

PC (Polycarbonate): with its ability to withstand high temperatures, PC is used to make bottles, containers and lids for foods that require sterilization. PC film has poor gas and vapor barrier properties; because the cost of PC is up to three times that of PP and PET, it is generally little used.

Properties. Gas and vapor barrier higher than PE and PVC but lower than PP and PET; transparent, with very high mechanical strength and rigidity, good abrasion resistance and unaffected by food components; withstands high heat (above 100°C).

3. Classification by plastic value (recycling value)

3.1. High-value plastics (high recycling value)

These are plastics currently collected and processed fairly thoroughly by the scrap market—mainly plastics in the type-1 (PET), type-2 (HDPE) and type-5 (PP) groups. Some typical examples include plastic bottles, broken tables and chairs, used toys, and so on.

3.2. Low-value plastics (low recycling value)

These are plastics with a low price in the scrap market, or that the scrap market does not buy at all. This type of plastic is often a mixture of many materials (plastic, paper or metal), difficult to separate and process, or plastic that has been recycled many times so that it has almost entirely lost its soft, flexible and load-bearing properties. Plastics with low recycling value are usually type 3 (PVC), type 4 (LDPE), type 6 (PS) and type 7 (other plastics). Some examples: nylon bags, candy wrappers, instant-noodle wrappers and foam boxes.

Figure. Instant-noodle wrappers are regarded as products of no value in the scrap market.

Chapter III. The State of Plastic Waste and Plastic Waste Management

1. Ocean plastic waste: sources, effects, current state and management directions

1.1. Introduction

Ocean plastic waste consists of plastic items produced or processed by humans that persist for a long time in the environment, deliberately discarded into the sea, rivers or beaches by people, or carried indirectly out to sea by rivers, wastewater, rainwater or wind.

Research by Li et al. (2016) confirmed that 80% of the plastic waste generated originates from land-based activities and the remaining 20% comes from ocean activities.

With their many shapes and structures, plastics are commonly found in different environments of the ocean. Together with the non-biodegradable nature of plastic, which causes it to persist for a long time in the environment, this leads to many different impacts.

Southeast Asia is one of the main contributors to the ocean plastic waste found in the environment globally. In a 2010 estimate, six ASEAN member states were listed among the top 20 countries with poor waste management, leading to plastic leakage into the ocean (Jambeck et al., 2015); that study estimated that about 4.8–12.7 million tonnes of plastic waste are dumped into the ocean each year, of which Vietnam alone discharges 0.28–0.73 million tonnes. Together with China, Indonesia, the Philippines and Thailand, Vietnam is responsible for more than half of the plastic entering the oceans (Ocean Conservancy and the McKinsey Center for Business and Environment, 2015).

1.2. Where does the plastic waste in the ocean come from?

The largest source of plastic in the marine environment is considered to be land (Li et al., 2016). In addition, plastic also originates from marine activities, coming mainly from cargo vessels (Horsman, 1982) and fishing vessels (Merrell, 1980; Coleman and Wehle, 1984; Pruter, 1987; Chen and Liu, 2013).

In 2015, Jambeck et al. published a major study on the amount of plastic waste entering the marine environment from land. These authors presented figures showing that each year a very large amount of plastic waste comes from coastal countries. Jambeck et al. (2015) appear to have provided a suitable basis for studying the harm of plastic waste to marine life and marine animals, and for research on preventing and reducing plastic waste in the marine environment.

1.3. Effects of plastic waste

Effects of plastic waste on organisms. Marine animals and birds often mistake fragments of plastic waste for their food (Derraik, 2002; Gregory, 2009; Boerger et al., 2010). At present, more than 260 marine species have been recorded as becoming entangled in or ingesting plastic fragments at sea (for example, turtles mistaking nylon bags for jellyfish).

With plastic fragments accumulating in the stomach, animals cannot absorb and store enough food, leading to declining fitness and even death by starvation. Several animals such as turtles, whales, birds and others have been recorded dying after mistaking marine debris for food.

Particularly in seabird species, given the habit of mother birds feeding their chicks, plastic particles are passed on to the chicks, causing them to contain more plastic than adult birds; they are therefore also more vulnerable and more likely to die (Gregory, 2009).

In addition, with the additives added to plastic products (such as polycyclic aromatic hydrocarbons (PAHs), hexachlorocyclohexane (HCH), etc.), these affect animals' reproductive hormones and increase the frequency of cancer-causing mutations. Coloring additives in plastic negatively affect the endocrine system and hormone regulation in the bodies of organisms.

Some recent studies have shown that plastic (both large plastic fragments and microplastics) can also bioaccumulate organic toxic substances—POPs including: dioxins, furans, PCBs, the pesticides toxaphene, DDT, aldrin, dieldrin, endrin, heptachlor, mirex, HCB, chlordane—and inorganic substances (lead, mercury, arsenic, etc.) from the ocean environment (Moore, 2008). Plastic waste therefore particularly accelerates the accumulation of toxic chemicals in the organisms that ingest it and in organisms along the food chain (Hirai et al., 2011).

Socio-economic effects. Plastic waste is a potential socio-economic threat because of its effect on coastal activities, reducing the economic benefits of fishing in coastal areas (Newman et al., 2015). Plastic waste is also a cause of change and even destruction of underwater habitats, coral reefs and seagrass; moreover, it is capable of transporting marine species from one area to another through the movement of plastic debris (Sheavly and Register, 2007). These marine species are carried to a new environment where they may endanger native species (Sheavly and Register, 2007). Plastic waste also endangers vessels. For example, nets, ropes or fishing gear can obstruct a vessel's operation (Newman et al., 2015), forcing the vessel to stop operating in order to repair parts or remove plastic when it becomes entangled or twisted around the propeller and rudder (Newman et al., 2015). Nylon bags are the most common cause of blockages and other problems in plumbing systems (Sheavly and Register, 2007).

Effects on humans. Studies have shown that plastic waste can affect human health through the food chain (Thompson et al., 2009; Galloway et al., 2017). Talsness et al. (2009) suggested that plastic waste is linked to cancer, reproductive health, imbalanced development in children, and immune dysfunction. A recent study by Gallo et al. (2018) showed that absorbing plastic waste causes phenomena such as DNA damage, changes in genes and proteins, cell coagulation, loss of cell viability, bone inflammation and organ damage.

1.4. Ocean plastic pollution along Vietnam's coast

With a coastline more than 3,000 km long and a sea area three times larger than its land area, plastic pollution of the ocean in Vietnam is hard to avoid; the source of this pollution comes from both land and ocean. With a dense network of rivers, these are the main route by which plastic waste is transported from inland out to the sea. The Soài Rạp River (Hồ Chí Minh City) is estimated to be among the world's 20 rivers discharging the most plastic waste into the ocean, at a volume of about 4,100 tonnes/year (Meijer et al., 2021). According to a survey by GreenHub along the coast during 2020–2021, plastic waste found along Vietnam's coast made up about 83.4%–99.05% of the total waste recorded. The survey also showed that a great many single-use plastic products and fishing-gear-related items were found along Vietnam's coasts. This reflects the consumption habits and awareness of the population as well as domestic waste-management practices.

The amount of litter is usually higher at beaches without regular cleanup activity, whether urban or rural, and whether tourist or non-tourist. In general, tourist beaches are cleaner than non-tourist beaches. Table 1 and Figure 1 present the ten most common types of litter found along Vietnam's coast.

Table 1 / Figure 1. The ten most common types of marine litter along Vietnam's coast (Source: Nguyen et al., 2022).

The coastal survey results also showed that most beaches in Vietnam fall within the polluted threshold, and some are even extremely dirty (Table 2); however, compared with some places in the Asia–Pacific region, Vietnam's coasts generally have lower litter density.

No.	Survey location	Surveyed beach	Coastal cleanliness level	Recorded litter density (items/m²)
1	Hải Phòng	Đồ Sơn	Extremely polluted	4.14
2	Hải Phòng	Cát Hải	Extremely polluted	0.56
3	Thừa Thiên – Huế	Thuận An	Extremely polluted	3.56
4	Đà Nẵng	Phạm Văn Đồng	Extremely polluted	2.44
5	Đà Nẵng	Nam Ô	Extremely polluted	0.67
6	Quảng Nam	Rạng	Extremely polluted	2.72
7	Khánh Hoà	Vĩnh Nguyên	Extremely polluted	1.71
8	Khánh Hoà	Mỹ Ca	Extremely polluted	9.60
9	Khánh Hoà	Bình Lập	Extremely polluted	18.99
10	Sóc Trăng	30/4	Extremely polluted	0.83
11	Sóc Trăng	Lai Hoà	Extremely polluted	0.41
12	Sóc Trăng	Hồ Bể	Extremely polluted	9.29
13	Phú Quốc	Sao	Extremely polluted	8.35
14	Phú Quốc	Trường	Polluted	1.51
15	Úc (Australia)	Cocos Island	Polluted	21.6
16	Indonesia	Henderson Island	Polluted	41.6
17	—	—	Moderate	—

Table 2. Cleanliness level and recorded litter density at surveyed beaches (Source: GreenHub coastal survey, 2020–2021). Note: this table was reconstructed from a heavily scrambled multi-column extraction; the alignment of density values and provinces to individual beaches is approximate.

2. The current state of microplastic (Microplastic) pollution

2.1. Introduction

Over the past decade, microplastic fragments in the marine and freshwater environment have become a prominent issue. There is growing interest in understanding the impacts of microplastics on natural organisms living in water, as these impacts are still not well understood. According to Arthur et al. (2009), microplastics are plastic fragments smaller than 5 mm in size.

Microplastics have many uses in daily life; for example, microbeads are used in personal-care products such as exfoliants. Microplastics are also used to deliver drugs in some medical applications (Browne et al., 2007). Furthermore, fibers shed from clothing and synthetic ropes are microplastics (Thompson et al., 2004; Browne et al., 2007), as are the particles used in cleaning ship hulls and large machinery (Browne et al., 2007). The concerning fact is that many microplastics are small enough to pass through wastewater treatment plants and enter aquatic ecosystems (Browne et al., 2007).

Based on their origin, microplastics can be divided into two main types: primary and secondary (Arthur et al., 2009). Primary microplastics include manufactured raw plastic materials, such as virgin plastic pellets and microbeads (Browne et al., 2007; Arthur et al., 2009), that enter the ocean via runoff from land (Andrady, 2011). Secondary microplastics are generated when larger plastic items (medium and large plastics) enter beaches or the ocean and undergo mechanical, photo- (oxidative) and/or biological degradation (Thompson et al., 2004; Cooper and Corcoran, 2010). This degradation gradually breaks larger fragments into smaller plastic pieces that ultimately become undetectable to the naked eye.

As a result, microplastics have been detected in many predatory animals at all trophic levels, from zooplankton (Sun et al., 2017) to invertebrates (Setälä et al., 2016), fish (Neves et al., 2015), birds (Provencher et al., 2018) and mammals (Nelms et al., 2019). Moreover, plastic-related toxicity—such as plastic additives or adhering pollutants absorbed within the plastic particles (for example, trace metals, endocrine-disrupting chemicals, POPs)—can affect species at higher trophic levels and human health through bioaccumulation and biochemical reactions across the food web (Wang et al., 2018). The impacts of microplastics on organisms have been demonstrated at various levels, such as causing oxidative stress and histological changes, altering feeding preferences and behavior, inhibiting egg incubation and hatching time, and reducing growth and survival rates (Cole et al., 2015; Lo and Chan, 2018; Wang et al., 2019). In addition, microplastics have also been found in humans, specifically in feces (Schwabl et al., 2019) and in blood (Leslie et al., 2022).

2.2. Research method

The results presented here are drawn from many published studies, and not every paper on microplastics has been included. Using the Google Scholar search tool, papers with the keyword "Microplastic" (or "vi nhựa") were retrieved from the database, and different environments—sea, estuary, river, lake and soil—were examined for microplastic research.

2.3. The current state of microplastic pollution in Vietnam

Microplastics in marine sediment/sand. Worldwide there have been many studies on microplastic pollution and its impacts. In recent years, however, Vietnam has only just begun to conduct research on it. For example, a 2019 study by Hà Thị Hiền et al. examined microplastics in mangrove sediment at the Ba Lạt estuary, northern Vietnam, where the Red River flows into the sea, with an average microplastic density of 81.4 microplastics/kg (Hiền and Cúc, 2021). Another study on microplastic pollution in tidal-flat sediment in the coastal area of Đa Lộc commune, Hậu Lộc district, Thanh Hóa province, yielded an average of 4,123 microplastics/kg of sediment (Dũng et al., 2020). This was followed by a study at Tiên Yên Bay, Quảng Ninh province, whose results showed that the surface-layer sediment of the Tiên Yên Bay area was contaminated with 236–1,324 microplastic particles/kg of sediment (Dực et al., 2020).

A study by Nguyen et al. (2020) at eight beaches in Đà Nẵng showed that synthetic fibers were the predominant type of microplastic, accounting for more than 99.2% of total microplastics; these fibers were distributed relatively evenly at all sampling sites, at an average concentration of 9,238 ± 2,097 microplastics/kg of dry beach sand, although they tended to be more abundant in the surface layer than in deeper layers. Blue (59.9%) and white (22.9%) were the most common colors of fibrous microplastics; notably, a large proportion of synthetic fibers (81.9%) were 300–2,600 μm in size, which may pose a threat to marine ecosystems and human health. Another study conducted at three beaches in Đà Nẵng—Mỹ Khê, T20 and Sơn Thủy—found total microplastic densities at the three beaches of Sơn Thủy, T20 and Mỹ Khê of 1,460 ± 758, 1,799 ± 370 and 29,232 ± 2,577 particles/kg of dry sediment, respectively; among these, microplastics smaller than 150 μm accounted for the largest proportion, and three polymers—PTFE [Polytetrafluoroethylene (Teflon)], EVOH (Ethylene vinyl alcohol) and PA [Polyamide (Nylon)]—predominated in the samples (Đỗ et al., 2021). This study also reinforced the results of Nguyen et al. (2020).

For the southern region specifically, Khuyen et al. (2021) surveyed microplastic pollution in marine sand at Cần Giờ; the results showed that the average concentration across all sampled sand was 60.22 ± 19.05 microplastics/kg of sand, and the most common form of microplastic (40–88%) was fragments, usually small in size (25–100 μm).

Microplastics in freshwater. The Saigon River is one of the most studied rivers, both for large plastics and for microplastics; one reason is that it flows through the most densely populated area in the country, along with the strong presence of textile and plastic industrial facilities around Hồ Chí Minh City. Lahens et al. (2018) assessed fiber and fragment pollution in the Saigon River using a grab-sampling method (for microfibers) and a 300-μm plankton net (for fragments); the concentrations recorded here were 172,000 to 519,000 fibers/m^3 and 10 to 223 fragments/m^3, respectively. The microplastics detected came in many different colors and shapes; the fragments were made mainly of polyethylene and polypropylene, while the fibers were made mainly of polyester.

In another study, Strady et al. (2021) assessed microplastic pollution in many rivers in Vietnam. Microplastic pollution showed a diversity of concentrations, from 2.3 microplastics/m³ in the Red River, 2.7 microplastics/m³ in the Hàn River and 3.9 microplastics/m³ in the Đồng Nai River, while much higher concentrations were measured in urban rivers and smaller rivers: from 93.7 microplastics/m³ in the Nhuệ River to 2,522 microplastics/m³ in the Tô Lịch River.

Urban rivers with high microplastic concentrations may owe this to the direct discharge of wastewater into these rivers, together with their low drainage flow. The results of this study were lower than those for the Saigon River (Lahens et al., 2018), in the stretch flowing through Hồ Chí Minh City, Vietnam's economic capital. For freshwater lakes, microplastic concentrations in reservoirs used for irrigation and domestic supply—such as Trị An Lake and Dầu Tiếng Lake—ranged from 1.5 to 2 microplastics/m³; these are the second- and third-largest reservoirs in the country and are little affected by industrial and urban activities. By contrast, inner-city lakes such as Công Viên Lake in Đà Nẵng and West Lake (Hồ Tây) in Hà Nội are strongly affected by urban activities, so microplastic concentrations are high—from 70 microplastics/m³ at Công Viên Lake to 611 microplastics/m³ at West Lake (Strady et al., 2021).

Microplastics in saltwater and estuaries. In the saltwater environment (sea, bay), microplastics have also been detected; however, depending on the survey location, their concentrations vary—for example, from a low of only 0.4 microplastics/m³ at Cửa Lục Bay in Quảng Ninh province to 28.4 microplastics/m³ at the Dinh River estuary. At the Dinh River estuary, the high microplastic concentration is linked to the discharge of untreated wastewater and to fisheries activities.

At Cửa Lục, Đồ Sơn and Hạ Long Bay, microplastic concentrations were 0.4, 0.7 and 0.8 microplastics/m³, respectively. The low microplastic concentration at Hạ Long Bay was surprising, given the important tourism and aquaculture activities in this area; it is possible that the choice of sampling site did not align with the specific evidence of the impact of aquaculture activities, since the samples were taken relatively far from the farms. In Bình Định province, microplastic concentrations were 3.2, 4.1 and 24.3 microplastics/m³ at Thị Nại Lagoon (2 sites) and Quy Nhơn Bay. This province also features aquaculture activities. Although aquaculture activity is lower than in Quảng Ninh, the microplastic concentration is higher; this may be because Thị Nại Lagoon is directly influenced by the Kôn River and the Hà Thanh River, which receive untreated domestic and industrial wastewater from industrial zones—likely the main input source of microplastics to the lagoon and bay, alongside fisheries activities (Strady et al., 2021). In the Cần Giờ area, the average microplastic concentration in seawater at Cần Giờ beach was 6.44 ± 2.98 microplastics/L, higher than at Đồng Tranh Cape, which had only 3.75 ± 2.04 microplastics/L. PE was the most abundant polymer among the microplastics detected (Khuyen et al., 2021).

Microplastics in organisms. Besides microplastic pollution detected in the water environment and in marine sediment/sand, the detection of microplastics in organisms is also a matter of concern, especially in seafood species that are a favorite food source for humans.

One of the first papers to report the presence of microplastics in organisms was that of Phuong et al. (2019); these authors reported detecting microplastics in green mussels (Perna viridis) collected at Tĩnh Gia, Thanh Hóa, at a recorded concentration of 2.6 microplastics/individual and 0.29 microplastics/gram of fresh tissue; the microplastics detected were predominantly PP (31%) and polyester (33%).

Another study, conducted by Gia Hằng et al. (2021), assessed the accumulation of microplastics in hard clams (Meretrix lyrata) at four clam-farming areas—Tân Thành, Ba Tri, Gành Hào and Ba Động—over three consecutive months from January to March 2020. The results showed that the average microplastic density for all samples collected was 13.79 ± 1.06 microplastics/10 g of clam meat. Spatially, microplastics were most concentrated at the Tân Thành clam-farming area in Tiền Giang province (18.80 ± 2.40 microplastics/10 g of clam meat), followed by the Ba Động area in Trà Vinh province (13.11 ± 2.59 microplastics/10 g) and the Ba Tri area in Bến Tre province (12.56 ± 1.35 microplastics/10 g). The Gành Hào area in Bạc Liêu province had the lowest microplastic density among the four clam-sampling areas (10.70 ± 1.36 microplastics/10 g). When comparing microplastic density accumulated in clam bodies over time, density was most concentrated in February (16.94 ± 1.37 microplastics/10 g), followed by January (15.80 ± 2.35 microplastics/10 g) and lowest in March (8.63 ± 0.90 microplastics/10 g).

Also in clams, but farmed in the lower Saigon River in the beach area of Cần Giờ, one study focused only on synthetic-fiber pollution in the different tissues of the clams. The results showed an average microplastic concentration of 3.6 ± 2.1 fibers/individual or 2.7 ± 2.4 fibers/g of fresh tissue. Microfiber accumulation was higher in the remaining tissues than in the gills and digestive tract (Kieu-Le et al., 2022).

3. The current state through photographs

As the first person to travel the length of the country "photographing waste," photographer Nguyễn Việt Hùng (Lekima Hùng) was awarded the title "Blue Ocean Ambassador" by the Ministry of Natural Resources and Environment (Bộ TN&MT).

In August 2018, from Hà Nội, Lekima Hùng began a journey by motorbike from north to south, through 39 provinces and cities (including 28 coastal provinces and cities). His trip lasted 43 days and captured, in film and photographs, more than 3,000 images documenting the state of environmental pollution caused by plastic waste along Vietnam's coasts, from the country's northernmost point (Sa Vĩ Cape, Quảng Ninh) to its final point (Cà Mau Cape).

4. Plastic Waste Management Policy

4.1. International policy on plastic waste management

- Resolution to End Plastic Pollution: Towards an International Legally Binding Instrument, issued by the United Nations Environment Assembly (UNEA) on 02/03/2022.

- International Convention for the Prevention of Pollution from Ships, MARPOL 1973/78 (Annex V), issued by the United Nations, entered into force 11/05/2016.
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, issued by the United Nations, effective for Vietnam 13/03/1995.
- United Nations Convention on the Law of the Sea, issued by the United Nations, effective 27/07/1994.

4.2. Vietnam's policy on solid-waste and plastic-waste management at the national level

National-level policies on solid-waste and plastic-waste management (updated August 2022):

- The amended Law on Environmental Protection 2020, No. 72/2020/QH14, passed by the National Assembly on 17/11/2020 and in force from 01 January 2022.
- The Law on Environmental Protection Tax, No. 57/2010/QH12, passed by the National Assembly on 15/11/2010 and in force from 01 January 2012.
- Resolution 579/2018/UBTVQH14 on the Environmental Protection Tax Schedule: stipulating the application of an environmental tax of 50,000 VND/kg on nylon bags.
- Resolution No. 09/NQ-CP of 03 February 2019, assigning the Ministry of Natural Resources and Environment as the unified state management agency for solid waste.

- Decision No. 1316/QĐ-TTg of 22 July 2021, approving the Scheme to strengthen plastic waste management in Vietnam.
- Decision No. 889/QĐ-TTg of 24 June 2020, approving the national action program on sustainable production and consumption for the period 2021–2030.
- Decision No. 1746/QĐ-TTg of 2019, promulgating the National Action Plan on Ocean Plastic Waste Management to 2030.
- Decision No. 491/QĐ-TTg of 7 May 2018, approving the adjustment of the National Strategy on Integrated Solid Waste Management to 2025, with a vision to 2050.
- Directive No. 41/CT-TTg of 1 December 2020 on a number of urgent measures to strengthen solid-waste management.
- Directive No. 33/CT-TTg of 20 August 2020 on strengthening the management, reuse, recycling, treatment and reduction of plastic waste.
- Consolidated Document 09/VBHN-BTNMT of 2019, consolidating the Decree on the management of waste and scrap, issued by the Ministry of Natural Resources and Environment.
- Circular 07/2012/TT-BTNMT of 2012, stipulating the criteria, order and procedures for recognizing environmentally friendly nylon bags, issued by the Minister of Natural Resources and Environment.
- Decision 849/QĐ-BTNMT of 2019 on the Plan to implement Government Resolution No. 09/NQ-CP of 03 February 2019 on unified state management of solid waste.
- Decision 2992/QĐ-BCT of 2011, approving the Master Plan for the development of Vietnam's plastics industry to 2020, with a vision to 2025, issued by the Minister of Industry and Trade.

4.3. Plastic-waste management policy relating to health and medicine

- Stockholm Convention on Persistent Organic Pollutants (POPs), issued by the United Nations; Vietnam has been a party since 22/07/2002.
- Directive No. 08/CT-BYT of 29 July 2019 of the Minister of Health on reducing plastic waste in the health sector, in force from 29/07/2019.
- Circular No. 34/2011/TT-BYT of 30 August 2011 of the Minister of Health, promulgating National Technical Regulations on hygiene and safety for packaging and utensils in direct contact with food, in force from 30/08/2011.

Chapter IV. The Harms of Plastic Waste

Every stage in the life cycle of plastic carries significant risks to human health.

1. The harm of plastic to human health

The stage of extracting and transporting raw fossil feedstock to produce plastic. Fossil fuels such as oil, gas and coal are the main raw materials, making up more than 90% of the composition of plastic. Extracting oil and gas (especially using hydraulic fracturing to extract natural gas) releases large amounts of toxic substances into the air and water. These toxins directly affect the skin, eyes and other tactile organs, the respiratory system, the digestive system, the liver, as well as the brain and nervous system. More than 170 chemicals used in hydraulic fracturing operations to produce plastic can cause health impacts, including cancer, neurotoxicity, and reproductive and immune-system suppression. Exposure to these toxins increases the rate of hospitalization for cardiovascular or neurological problems.

The stage of petroleum refining and the production of synthetic resin and additives. Converting fossil fuels into plastic and using additives releases carcinogens and other toxic substances into the air, water and soil, with a range of adverse impacts on human health. The documented impacts include nervous-system impairment, reproductive and developmental problems, cancer, and genetic effects leading to conditions such as low birth weight in newborns, cancer and leukemia. Workers in the industry and communities living near plastic production facilities are the groups at highest risk, facing the threat of chronic exposure and acute risks. Plastic production has a greater impact on the health of poor communities and vulnerable groups, such as women of reproductive age and children.

Direct exposure through contact, ingestion or inhalation. Microplastics and the chemicals in consumer products and plastic packaging have adverse effects on human health. Using plastic products leads to ingesting or inhaling large amounts of microplastic particles and hundreds of toxic substances, whose harms include developmental effects, endocrine disruption and cancer. Microplastics entering the human body can lead to a range of health impacts, including inflammation (linked to cancer, heart disease, inflammatory bowel disease, rheumatism, etc.), genotoxicity (damaging the genetic information in cells and causing mutations that can lead to cancer), oxidative imbalance (leading to chronic diseases such as cancer, diabetes, rheumatism, cardiovascular disease, chronic inflammation and stroke), apoptosis (programmed cell death linked to many types of disease, such as cancer) and necrosis (cell death linked to cancer, autoimmune diseases and neurodegeneration). Over time, these impacts can also lead to tissue damage, fibrosis and cancer.

Exposure spreading through the environment and within the human body. Most additives in plastic production are not bonded to the polymer molecules and easily escape into the surrounding environment, including the air, water, food or bodily tissues. As plastic particles gradually degrade, new surface layers are exposed, drawing additives from the interior out to the surface of the particle. Some plasticizers, such as DEHP and BPA, can cause reproductive toxicity. Benzene and phenol are both mutagenic: they alter an organism's genetic material (usually DNA), increasing the frequency of mutations. Some harmful additives include flame retardants and lead-based heat stabilizers. Other toxic chemicals thought to leach from plastic polymers include antioxidants, UV stabilizers and surfactants.

2. The harm of plastic waste to the environment

In the natural environment, plastic waste is very difficult to decompose. Depending on the type of plastic, it takes different amounts of time to decompose. In the early 1960s, the first records of plastic waste came from the carcasses of birds collected on the coast. Today, plastic waste is found commonly throughout the oceans, from coastal waters and tidal flats down to the deep seabed, from the poles to the equator. The indiscriminate discarding of plastic waste leads to environmental pollution:

Effects on the environment (soil). Plastic waste contains many toxic substances, additives and heavy metals. When placed in open dumps and landfills, these toxins penetrate the soil and kill many beneficial soil organisms such as earthworms, microorganisms, many invertebrates, and frogs and toads, reducing the soil's biodiversity and giving rise to many crop-destroying pests. The rampant use of nylon bags in daily life can form "nylon walls" that partition the soil, restricting the decomposition and synthesis of nutrients, reducing soil fertility and lowering crop yields.

Effects on the air environment. Methane (CH_4) and Carbon Dioxide (CO_2) are two greenhouse gases released during the microbial decomposition of plastic after landfilling. Air pollution is one of the major environmental threats to public health, and it causes more than 6 million deaths from environmental pollution. Openly burning plastic and plastic products releases pollutants such as heavy metals, dioxins, PCBs and furans, which, when inhaled, can pose health risks, especially respiratory disorders. The impact of plastic on air pollution in developing and poor countries around the world is by no means small, and the effect on future generations could be very large.

The conservation organization Ocean Conservancy and the consulting firm McKinsey forecast that by 2025, for every 3 tonnes of fish in the world's oceans there will be 1 tonne of plastic waste.

Effects on water resources. Out of habit, many people dump waste at the banks of rivers, lakes, ponds and drainage ditches. After decomposing, plastic waste directly and indirectly affects the quality of surface water and groundwater in the area. Plastic waste can also be washed by rainwater into ponds, lakes, rivers, streams and canals, polluting the surface water there; over time this reduces the area of ponds and lakes, diminishes the water's self-cleaning capacity, obstructs flows and clogs drainage systems. The consequence is the destruction of the aquatic ecosystems in these ponds and lakes.

Effects on marine organisms and ecosystems. Of the waste found in the ocean, an estimated 80% is made of plastic. Most plastic floats on water, so a large amount of plastic debris accumulates on the sea surface and is carried inshore by waves or currents. As a result, plastic makes up a significant proportion (50–80%) of the total waste found on beaches. Some plastic waste can sink to the seabed, even to depths of thousands of meters, where its degradation rate is especially slow because of the darkness and low temperature.

Under the worst-case scenario forecast by the conservation organization Ocean Conservancy and the consulting firm McKinsey, by 2025, for every 3 tonnes of fish in the world's oceans there will be 1 tonne of plastic waste.

Animals come into contact with plastic waste mainly through ingestion or entanglement. Nylon bags floating on the ocean resemble jellyfish—a favorite food of large marine creatures—not only in shape but also in smell. Once in the ocean, over time plastic waste takes on the smell of food. This process occurs when bacteria and algae act on the plastic waste, soon causing the plastic to lose its original chemical odor and take on a more natural smell. This is regarded as an olfactory "trap," making ocean animals—especially sea turtles—liable to swallow it unintentionally. Seabirds are a similar victim, as they often mistake microplastics for squid or fish. Plastic waste often contains toxic substances such as flame-retardant compounds, PCBs, polystyrene and BPA. Poisoning by plastic can occur in a great many ocean organisms, because plastic is found both above the water surface and in the deep seabed, along with its ultra-fine microplastic component.

Statistics show that more than 260 species—including invertebrates, sea turtles, fish, seabirds and mammals—have been found ingesting or entangled in plastic fragments, leading to impaired digestion and movement, reduced reproductive output, and death. In addition to large marine organisms, coral reefs are also destroyed by trawl nets and other plastic products along the seabed. Typically, discarded fishing nets, also known as "ghost nets," trap marine animals, causing them to gradually die of starvation.

Beyond mechanical impacts, microplastic particles (size <5 mm) detected in the digestive systems of marine animals are increasing steadily. Plastic fragments also transfer toxic substances into the food chain. Laboratory exposure studies show that Phthalates and BPA affect reproductive capacity in all the animal groups studied and impair development in crustaceans and amphibians. Through laboratory studies of the impacts of plastic, it is possible to identify their effects on wild populations of organisms in nature. These substances not only affect the organisms that consume them directly but can also accumulate in the food chain and affect higher-order consumers, or even, in some cases, affect human health.

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