Plastic Oceans

Mr. McGuire: I want to say one word to you. Just one word.
Benjamin: Yes, sir.
Mr. McGuire: Are you listening?
Benjamin: Yes, I am.
Mr. McGuire: Plastics.
Benjamin: Exactly how do you mean?
Mr. McGuire: There's a great future in plastics. Think about it. Will you think about it?
Benjamin: Yes, I will.
– The Graduate, 1967

Marine debris – trash in our oceans – is a symptom of our throw-away society and our approach to how we use our natural resources.
– Achim Steiner

You're enjoying your day at the beach when suddenly a gust of wind blows your plastic bags and plates off of your blanket. You try and catch them as the various pieces lurch erratically across the sand. You recover a few pieces but some of them get away and are carried by the breeze down the coast. At the end of the day a plastic water bottle, a spoon or two, maybe a shovel or Frisbee get left behind in the sand.

Some of these plastic objects may be picked up and thrown out, but some of them remain there and are exposed to the environment. The sun, wind and sand slowly do their work making the plastics more brittle and breaking them down into smaller pieces. Some of these items, or their smaller fragmented parts, make their way into the ocean where sunlight and wave action continue to break them up into smaller and smaller pieces. Through ocean currents, some of this plastic waste collects on distant shores, and some ends up in one of the enormous ocean whirlpools where it accumulates and continues to break apart.

Floating garbage off the shore of Manila Bay in the Philippines.

Plastic products escape from overflowing trash cans, piles of garbage at municipal dumps, and through many other circumstances. They make their way through streams, rivers and storm water to the ocean.[1] Styrofoam food containers, sunglasses, bottle caps, drinking straws, beach coolers, fishing lines, and a wide assortment of other consumer products gradually make their way to the ocean where they are worn down by time and the elements. That floating plastic bottle will eventually disappear from view, but its ever smaller particles will still be in the environment.

Plastic is a synthetic organic polymer that has been incorporated into modern life over the last century. Its characteristics of durability, flexibility, strength, versatility, light weight and relatively low cost of production have contributed to its entering all aspects of everyday life. There are many types of plastics and products that use this manmade material that come in a huge number of shapes, sizes, and colors. Some common types of plastic are: polystyrene (PS, aka Styrofoam) used for take-out food containers; polyethylene terephthalate (PET) used for soda bottles; polyethylene (PE) used for plastic bags; high-density polyethylene (HDPE) used for detergent bottles; polyvinyl chloride (PVC) used for plumbing pipes; polypropylene (PP) used for drinking straws; polyamide (PA, aka nylon) used for toothbrushes; and polyester (PES) used for clothing.[2]

> *Plastics have become increasingly dominant in the consumer marketplace since their commercial development in the 1930s and 1940s… The largest market sector for plastic resins is packaging; that is, materials designed for immediate disposal. In 1960, plastics made up less than 1% of municipal solid waste by mass in the United States; by 2000, this proportion increased by an order of magnitude. By 2005, plastic made up at least 10% of solid waste...*[3]

Worldwide plastic production began just after World War II, increasing from 2.3 million tons in 1950 to 162 million in 1993 and to 448 million by 2015.[4] Since the 1940s a total of about 9.2 billion tons of plastic have been produced.[5] Of that amount 6.9 billion tons have become waste and with only about 9% of discarded plastic having been recycled, this leaves 6.3 billion tons sitting in landfills and in the environment,[6,7] equal to the weight of over 17,200 Empire State Buildings.[8]

In 2010, the 6.4 billion people living in countries within 50 kilometers (31 miles) of an ocean coast produced an estimated 2.5 billion metric tons of garbage, of which approximately 11% or 275 million metric tons was plastic. An estimated 1.7 to 4.6% (or 4.8 to 12.7 million metric tons) of plastic waste generated by those countries entered the ocean in 2010.[9] To put things into perspective, the largest living animal in the world is the blue whale with an average adult weight of about 115 metric tons,[10] meaning that about 41,700 to 110,400 blue whale-weight equivalent of plastic enters our oceans each year.

Out of 20 countries, China generates the largest amount of plastic debris that enters the ocean at 1.32–3.53 million metric tons per year. The United States has the lowest amount of marine plastic debris at 0.04–0.11 million metric tons per year. However, the United States has by far the highest amount of overall waste generated per person, at an average of 2.58 kilograms (5.7 pounds) per person per day.[11]

Recent work by researchers at the *Ocean Cleanup*, a Dutch foundation developing new technologies for ridding the oceans of plastic, found that two thirds of oceanic plastic debris comes from the 20 most polluting rivers. The overwhelming majority of these rivers are in Asia, with the Yangtze River in China being the largest culprit, dumping some 330,000 tons of plastic into the East China Sea every year.[12]

Shore cleanups have been organized by the *Ocean Conservancy* since 1986. In 25 years a total of 166,144,420 items were collected in 152 different countries and locations. Plastic items, such as plastic bags and bottles and six-pack holders, accounted for 11% of the total amount of collected

waste. Over those 25 years, 957,975 six-pack holders alone were collected.[13] By far the largest single item collected was cigarette butts at 52,907,756. In fact, as many as 5.6 trillion cigarettes or 766,571 metric tons (844,000 tons) of butts (over 6,500 blue whales' worth) are deposited into the environment worldwide every year.[14] Cigarette butts are made of compressed, plasticized cellulose acetate wrapped in an external paper layer and because of this, they degrade very slowly.[15]

> *The majority of cigarette waste that ICC [International Coastal Cleanup] collects from beaches is the result of improper disposal. "Many people, even smokers, are not aware that the cigarette filter is comprised of thousands of little particles of plastic," says Nicolas Mallos, director of Trash Free Seas Program at the Ocean Conservancy in Washington DC. "One solid filter ends up being thousands of tiny fibres that can be released into the marine environment."*[16]

This enormous amount of plastic entering the environment is a considerable problem as plastics don't decompose like natural substances. Wood, grass, and food leftovers all undergo a process known as biodegradation. This means they are all decomposed by bacteria and fungi into environmentally beneficial compounds. These same natural processes don't act on plastics and so plastic products remain in the environment for a very long time. While there is no agreed figure for the time that plastic takes to fully degrade it could be hundreds of years.[17] Plastics have been estimated to last up to 600 years in the marine environment, depending upon water conditions, ultraviolet light penetration and the level of physical abrasion.[18] Plastic degeneration happens far faster in a hot abrasive environment, like a beach, than in the colder water of the ocean, but in any case, objects eventually split up into microscopic pieces of plastic. The main inputs of plastics into the sea come from beaches and land-based sources like rivers, stormwater runoff, wastewater discharges, or transport of land litter by the wind.[19]

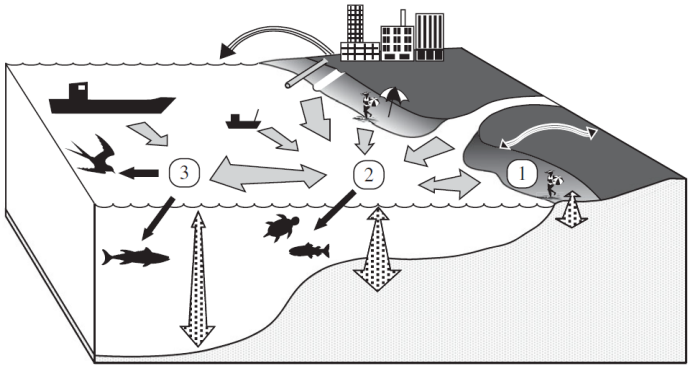


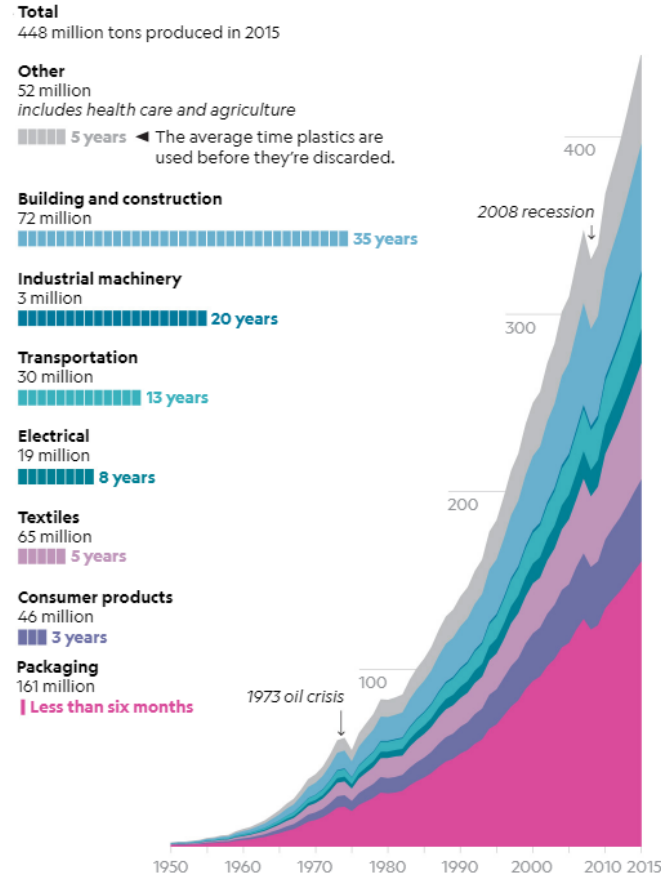
Diagram showing the main sources and movement pathways for plastics in the marine environment, with sinks occurring (1) on beaches, (2) in coastal waters and their sediments and (3) in the open ocean. Curved arrows depict wind-blown litter, grey arrows waterborne litter, stippled arrows vertical movement through the water column (including burial in sediments) and black arrows ingestion by marine organisms.

All of this plastic waste continues to accumulate in our oceans. By 2025 there will be an estimated 100 to 250 million metric tons of cumulative plastic debris.[20] Given that there are 10,000 to 25,000 blue whales in the world's oceans,[21] this means that by that year there will be 35 to 217 times more plastic by weight than there are blue whales. In other words, this is also equal to 300 to 750 times the weight of the Empire State Building.

Plastic waste will continue to grow with increased population and increased per capita consumption associated with economic growth, especially in urban areas and developing countries, with "peak waste" not expected to be reached before the year 2100.[22] A million plastic bottles are bought around the world every minute. That

number is projected to jump another 20% by 2021, all due to an insatiable desire for bottled water and the spread of a Western "on-the-go" culture. More than 480 billion plastic drinking bottles were sold in 2016 across the world, which is up about 60% from just 10 years earlier. If placed end to end the bottles would extend more than halfway to the sun.[23] Major drink brands produce the greatest numbers of plastic bottles. Coca-Cola alone produces an estimated 110 billion throwaway plastic bottles every year, which equates to an astounding 3,490 per second.[24]

Other consumer products are also flooding the oceans. Scientists estimate that 437 million to 8.3 billion plastic straws are slowly disintegrating on all of the world's coastlines.[25] Each year, an estimated 500 billion to 1 trillion plastic bags are used worldwide. That is equal to as many as 32,000 plastic bags being used per second with only about 1 in 200 being recycled.[26] Single use coffee pods also create a staggering amount of waste. In 2014, the discarded K-Cups for the Keurig Single Serve Coffee Maker were enough to circle the earth more than 10 times.[27] Sachets' tear-off packets that once held a single serving of shampoo, toothpaste, coffee, condiments, or other products are sold by the millions. Roughly 40% of the now more than 406 million metric tons (448 million tons) of plastic produced every year is disposable.[28]



Global plastic production by industry in millions of tons.

Once in the ocean, the environmental fate of plastic products primarily depends on the plastic density, which influences buoyancy and its position in the water column. Plastics that are denser than seawater, like PVC, will sink, while those with a lower density of polyethylene (e.g. plastic bags) and polypropylene (e.g. drinking straws) will tend to float in the water column. Dr Shoichi Oshima noted an example of plastics floating in the water column by observing…

> *…a fleet of flimsy white plastic, supermarket shopping bags, up-ended and suspended at depths of 2000 metres [1.25 miles], and drifting like an assembly of ghosts.*[29]

Because plastics don't decompose they simply get smashed into smaller and smaller pieces. The pieces smaller than 5 millimeters (just under two-tenths of an inch) or about the size of a pencil eraser have been termed microplastics.

A 2016 study estimates that there are already 245,000 metric tons (270,000 tons) of microplastics composed of 5.25 trillion particles in our oceans.[30] Another study estimated that there could be up to 51 trillion pieces of microplastics floating in the oceans.[31] That's roughly 7,000 plastic particles for every person on the planet. While most microplastics are as a result of the wearing down of larger products like water bottles, there are sources of direct microplastic pollution.

> *The majority of microplastics in the oceans are secondary products derived from degradation and fragmentation of mesoplastics or larger fragments; primary microplastics, introduced directly into the oceans via runoff, are manufactured as micron-sized particles typically used as exfoliants for cosmetic formulations, in industrial abrasives and 'sandblasting' media, in textile applications and synthetic clothes.*[32]

Microbeads made of various plastic particles are used in hundreds of products that are designed to be discarded down the drain. They are often used as abrasive scrubbers in face washes, body washes, cosmetics, cleaning supplies, and even in toothpastes. [33] A single bottle of facial cleanser can contain 350,000 microbeads.[34]

Exposure to wind, waves and sun degrades plastic trash into tiny plastic particles that soak up pollutants. These 'microplastics' made up 80% of total plastic samples collected in a recent survey of Lake Erie.

An estimated 800+ trillion of these particles are to be washed down US pipes every day.[35] Many of these are recovered in waste water treatment and end up as sediment that settles at the bottom of processing tanks. This waste is often applied as land fertilizer that may eventually enter aquatic habitats via runoff or become airborne and distributed throughout the environment as the sludge dries out. The airborne plastics can then be breathed in by animals and people, potentially delivering chemicals to the lower parts of their lungs and they may even cross into the circulatory system.[36]

More than 10 million metric tons (11 million tons) of sewage sludge was produced in waste water treatment plants in the European Union (EU) in 2010. Every kilogram of this sludge has been found to contain thousands of microplastics, most of which are plastic fibers. The microplastic-laden sewage sludge that is then spread on fields and forests as fertilizer will no doubt cause further accumulation of microplastics in the environment.[37] Not all microbeads are separated via waste water treatment. As many as 8 trillion of these particles escape into the Earth's waterways daily just in the United States. That's enough to cover more than 300 tennis courts daily or over 21.4 square kilometers (8.3 square miles) yearly.

In 2001, a high concentration of plastic debris was first observed in the North Pacific central gyre or whirlpool. It was termed an "ocean garbage patch." Currently, there are a total of five ocean garbage patches that have been identified in the North Atlantic, South Atlantic, South Indian, North Pacific and

South Pacific. The total estimated combined surface size of these patches is 15,916,000 square kilometers (or 6,145,000 square miles), or roughly double the size of Australia.[38] The Great Pacific Garbage Patch alone is made up of an estimated 1.8 trillion pieces of plastic with 94% being microplastics.[39] Julia Reisser, a researcher based at The University of Western Australia noted that traversing the large rubbish-strewn whirlpools in a boat was like sailing through "plastic soup."[40]

> *"You put a net through it for half an hour and there's more plastic than marine life there," she said. "It's hard to visualise the sheer amount, but the weight of it is more than the entire biomass of humans. It's quite an alarming problem that's likely to get worse. Bigger fish eat the little fish and then they end up on our plates. It's hard to tell how much pollution is being ingested but certainly plastics are providing some of it."*

Even the remote and once pristine Arctic Ocean is being infiltrated with plastic. The first survey of this region in 2013 found roughly 300 billion pieces of floating plastic. Most of these pieces are tiny but visible to the naked eye.

> *"Our data demonstrate that the marine plastic pollution has reached a global scale after only a few decades using plastic materials," said Andrés Cózar Cabañas, a biologist at the University of Cádiz. It is, he said, "a clear evidence of the human capacity to change our planet. This plastic accumulation is likely to grow further."*[41]

Over 630 species have been recorded interacting with plastic debris.[42] Seabirds, sea snakes, sea turtles, penguins, seals, sea lions, manatees, sea otters, fish, crustaceans and half of all marine mammals are the most impacted by macro debris.[43] They can choke on grocery bags and become entangled in six-pack rings and fishing nets. Studies have shown that fish and other marine life such as birds eat these plastics which can cause damage to their digestive systems. Plastics that stay in the gut make the animal feel full, which can lead to malnutrition or even starvation. In one experiment, grass shrimp were fed a diet of brine shrimp mixed in with polypropylene plastic beads. After six days, all of the shrimp were dead. They stopped eating because their guts were blocked with the plastic which caused them to starve to death.[44]

Each year an estimated 1 million seabirds, 100,000 sea mammals and countless numbers of fish are killed due to plastic pollution.[45] An autopsy of a young male sperm whale that had washed up dead on the southeastern coast of Spain was found to have 29 kilograms (65 pounds) of "plastic trash crammed into the dead whale's stomach and intestines, including dozens of plastic bags, chunks of mangled rope and glass, a large water container and several 'sacks of raffia [a fiber derived from palm trees].'" The whale died because its digestive system had become lethally impacted or infected.[46] A young whale washed up in the Philippines that died of dehydration and starvation after having eaten 40 kilograms (88 pounds) of plastic bags made up of "40 kilos of rice sacks, grocery bags, banana plantation bags and general plastic bags. Sixteen rice sacks in total."[47] Around the world discoveries are being made of dead whales washed ashore having been killed by eating plastic.[48,49] Most of the endangered sperm whales that have been found dead in the eastern Mediterranean since 2001 have been killed by plastic debris.[50]

> *Post-mortem examinations on nine of 24 [sperm whale] carcasses found in Greek waters revealed that the animals experienced slow and painful deaths after their stomachs were blocked by the large amounts of plastic they had ingested.*

By being ensnared in or eating macro plastics, large organisms such as birds can have fatal but also sublethal effects. These include a compromised ability to capture and digest food, sense hunger and/or escape from predators, decrease of body condition and impaired locomotion, including migration. In 1960, plastic was found in the stomachs of fewer than 5% of seabirds. By 1980 that number had jumped to 80%, and by 2015 it was 90%.[51] According to one estimate, by 2050 almost all seabirds will have ingested plastic.[52]

Twisted masses of lost, but fairly intact nets and fishing lines can retain the ability to ensnare fish and other species for long periods of time. This inadvertent capture of sea life has been termed "ghost fishing." Hundreds of kilometers of nets and lines estimated at 580,000 metric tons (640,000 tons or over 5,000 blue whales worth) are lost in the ocean every year.[53] About half the weight of the Great Pacific Garbage Patch is made up of fishing nets and other fishing industry gear, including ropes, oyster spacers, eel traps, crates, and baskets.[54] Due to the resilient nature of the materials used to produce this fishing gear, they can and will keep ghost fishing for multiple decades, possibly even for centuries.

> *Prior to the 1950s, rope and cordage used in all marine activities, including fisheries, was made of natural fibres—typically Indian or Manila hemp and cotton, and it was often strengthened with a coating of tar or strips of worn canvas. These materials lose their resilience in usage and if lost or discarded at sea tend to disintegrate quickly... over the past 50+ years these natural fibres have been replaced by nylon and other synthetic materials that are generally buoyant and far more endurable.*[55]

It's impossible to estimate how many marine animals are killed each year by "ghost fishing." However, a variety of reports suggests staggering numbers—many of them of commercially valuable or endangered species. Off the coast of Washington state in Puget Sound, lost fishing gear is thought to kill more 3.5 million animals a year, including nearly 25 seals, porpoises and other marine mammals every week.[56]

Besides floating particles, microplastics also accumulate on the seafloor, posing an additional risk to those ecosystems. Some plastic flakes drift like "marine snow" down the water column where fish can consume them. Other bits fall farther to the muddy bottom where they are gobbled up by grass shrimp and other creatures. Still other plastic pieces wash up onto beaches and salt marshes where they become food for burrowing worms and filter feeding oysters. On some beaches on the Big Island of Hawaii, as much as 15% of the sand is actually grains of microplastic.[57]

Some may find it surprising because of plastic's buoyancy, but a significant amount reaches the deep seafloor which is the largest marine habitat on the planet. Once in the deep sea plastic can persist for thousands of years.[58]Microplastics in the form of microfibers constructed from modified acrylic, polypropylene, viscose (rayon), and polyester have been found in deep-sea organisms.[59]

PCBs (polychlorinated biphenyls) and PDBEs (polybrominated diphenyl ethers) that were commonly used as electrical insulators and flame retardants were banned in the United States in 1979. The global production of these substances is estimated to have been about 1.3 million metric tons. They have been found in high concentrations in crustaceans in the deep ocean.[60] The surface area of microplastics allows them to absorb pollutants from the surrounding ocean water. Plastic debris accumulates pollutants such as PCBs up to 100,000 to 1,000,000 times the levels found in seawater.[61] Japanese scientist Yukie Mato demonstrated that plastics bind to chemicals in seawater and concentrates them. DDE (a breakdown product from the insecticide DDT), PCBs, and other endocrine disrupting chemicals were each found to be one million more times concentrated on plastic beads than the seawater that they were placed into.[62]

The chemical ingredients in 50% of plastics are listed as hazardous by the *United Nations' Globally Harmonized System of Classification and Labeling of Chemicals*.[63] Bisphenol-A (commonly known as BPA) and phthalates, are called "everywhere chemicals" because they are so common and used in making countless plastic products. Plasticizers are commonly added to increase plastics flexibility, flame retardants reduce the spread of combustion, and colorants and other added materials modify basic plastic properties.

BPA has been recognized since the 1940s as an endocrine disrupting chemical that interferes with normal hormonal function.[64] Researchers have linked phthalates, which are used as plasticizers, to asthma, attention-deficit hyperactivity disorder, breast cancer, obesity and type II diabetes, low IQ, neurodevelopmental issues, behavioral issues, autism spectrum disorders, altered reproductive development, and male fertility issues.[65] These plastic additives and pollutants might be released when they are eaten by a wide variety of marine organisms. In 2018, "surprising levels" of phthalates were found in wild bottlenose dolphins who are high up on the food chain.[66]

> *Commonly used additives, including phthalates, bisphenol A (BPA), alkylphenols, polybrominated diphenyl ethers are hazardous to biota [ocean animal and plant life] acting as endocrine-disrupting chemicals that can mimic, compete with, or disrupt the synthesis of endogenous [growing within the body] hormones. These compounds have been measured at high concentrations in plastic fragments sampled both at remote and urban beaches, as well as in those floating in the open ocean.*[67]

Bacteria and other microbes have been found to also live on microplastic particles. The plastic fragments help to disperse these organisms throughout the environment while the organisms simultaneously influence the leaching of contaminants from these plastics. Seabirds that have ingested microplastics have been found to have elevated amounts of PCBs and other persistent organic contaminants.[68] Researcher from the National University of Singapore found more than 400 types of bacteria on 275 pieces of microplastic collected from local beaches. They included microbes that are linked to the bleaching of coral reefs and that cause wound infections and gastroenteritis in humans.[69]

It has already been shown that microplastics are ingested by large marine organisms such as whales.[70] Plastic debris and fibers from textiles have also been found in hundreds of species globally,

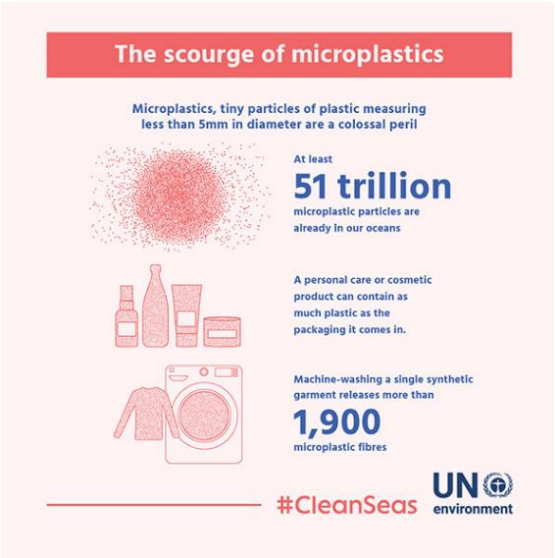
including many species of fish.[71] These include swordfish and tuna, and bivalves[72], such as mussels and oysters.

In 2015 scientists examining rivers found as many as 111 microscopic pieces of plastic in a single fish.[73] That result would later seem miniscule when a 2018 study of the River Tame, the main river of the West Midlands of England, exposed more than 500,000 microplastic particles per square meter in the top 10 centimeters of river bed.[74] That is a shocking 5,000,000 particles per cubic meter or almost 6,000,000 per cubic yard buried in the bottom of the river.

> *More than 1,000 small pieces of plastic per litre were found in the River Tame... The River Thames in London was found to have about 80 microplastic particles per litre, as was the River Cegin in North Wales. The Blackwater River in Essex had 15. Ullswater has 30 and the Llyn Cefni reservoir on Anglesey 40.*[75]

A 2018 study in *Frontiers in Marine Science* found microplastics, in particular plastic fibers such as those used in textiles, in the stomachs of 73% of mesopelagic fish caught in the Northwest Atlantic.[76] The mesopelagic is an ocean zone at a depth of 200 to 1000 meters (660 to 3300 feet) with the fish from that zone serving as a food source for a large variety of marine animals, including tuna, swordfish, dolphins, seals, and seabirds.

Studies have demonstrated that quantities of microscopic plastic fragments and fibers associated with plankton in surface waters have significantly increased since the 1960s with these materials being dispersed through the water column. Their widely distributed occurrences suggest environmental impacts whose magnitude and significance have yet to be fully appreciated. Fragmentation through environmental exposure turns larger plastics into fine powders that pass from view and are soaked up into the environment. More microplastics and their associated toxins continue to accumulate in the oceans and ultimately in the entire environment causing irreversible harm. Their extremely small size makes it exceptionally difficult, if not impossible, to remove them from the enormous open ocean environments.



The scourge of microplastics.

The hazardous cocktail of pollutants associated with plastics can be transferred to fish and other sea life. When mammals, such as seals or people, eat marine animals that have consumed this marine debris, there is the potential to increase their own burden of these hazardous chemicals.[77] This raises important questions regarding the bioaccumulation and biomagnification of chemicals and the consequences for human health. Recent studies show that humans are indeed ingesting microplastics from seafood, with 100% of mussels sampled from UK coastlines and supermarkets containing microplastics or other debris such as

cotton and rayon.[78] Scientists believe microplastic consumption by people eating seafood in Britain was likely "common and widespread".

> *When consuming an average portion of mussels (250 g wet weight) one consumes around 90 particles. An average portion of 6 oysters (100 g wet weight) contains around 50 particles... European top consumers will ingest up to 11,000 microplastics per year, while minor mollusc consumers still have a dietary exposure of 1800 microplastics per year. Once inside the human digestive tract, intestinal uptake of the ingested particles may occur.*[79]

> *"This is a wake-up call to the fact that our waste management systems are not as tight and advanced as they should be, and that might be coming back to haunt us through the food chain," said Chelsea Rochman, a postdoctoral fellow at the University of California, Davis.*[80]

As might be expected, plastic contamination is already being found in other places besides seafood. Analysis of a variety of consumer sea salt brands showed they also contain plastics.[81] While the plastic particle amounts found are currently low, very small particles, which probably will be in even higher concentrations, were not measured, due to study limitations. Also, the detected low quantities of plastic are likely to greatly increase over time as ocean plastic loads continue to accumulate and plastics continue to splinter. Microplastics have also been found in 90% of the table salt brands worldwide with Asian brands having especially high amounts.[82] Through salt alone the average adult consumes approximately 2,000 microplastics per year. Erik van Sebille, an oceanographer at *Utrecht University* in the Netherlands who studies global ocean circulation and plastic pollution, noted that:

> *"Over the last few years, whenever scientists have gone out to look for plastic in the ocean, they have almost always found it. Whether on the remote ocean floor, in the ice in the Arctic, in the stomachs of seabirds and fish, or now in sea salt. Plastic in the ocean is an atrocity, a testament to humanity's filthy habits."*[83]

Dr Sherri Mason collaborated with researchers at the *University of Minnesota* to examine microplastics in salt, beer and drinking water. Dr Mason found that Americans could be ingesting upwards of 660 particles of plastic every year. It is thought that the majority of this plastic contamination comes from microfibers and single-use plastics such as water bottles.[84] A small study in 2018 found that microplastics have already been detected in human waste suggesting they are widespread in the food chain.[85]

The sea salt was not only contaminated with plastics, but it was also tainted with pigments associated with plastics. Victoria blue is commonly used as a coloring agent in polyacrylic fibers. Lead chromate (yellow) pigment is a toxic compound that has extensive applications in paints and plastic industries. Lead chromate pigment has been associated with cancers, cerebrovascular (brain blood vessels) disease, and nephritis (inflammation of the kidneys) in humans. The amounts found were low, but like the plastic particles found they are likely to continue to greatly increase over time.

Most common plastics have also been found to discharge the greenhouse gases methane and ethylene when exposed to sunlight.[86] Polyethylene, used in shopping bags, was found to be the most prolific emitter of both gases. David Karl, senior author of a study that examined this phenomenon noted,

> *"Plastic represents a source of climate-relevant trace gases that is expected to increase as more plastic is produced and accumulated in the environment. This source is not yet budgeted for when assessing global methane and ethylene cycles, and may be significant."*

Other studies have shown that plastics have not only spread throughout the aquatic environment but are also ending up in products such as honey[87] and beer.[88] A 2017 study found that 83% of the world's tap water is already contaminated with microscopic plastic fibers.[89] The United States had the highest level of contamination at 94% of samples collected at various sites.[90] Another study found that 93% of leading brands of bottled water were contaminated with plastic debris, including nylon, polyethylene terephthalate (PET) and polypropylene, which are used to make bottle caps.[91]

Recent studies show that the fish that hatched in waters with high quantities of microplastics were "smaller, slower, and more stupid" than those that hatched in clean waters, making them easier targets for predator fish. Disturbingly, the fish actually choose to eat plastic instead of their normal food.

> *"They all had access to zooplankton and yet they decided to just eat plastic in that treatment. It seems to be a chemical or physical cue that the plastic has, that triggers a feeding response in fish," Dr Lonnstedt told BBC News. "They are basically fooled into thinking it's a high-energy resource that they need to eat a lot of. I think of it as unhealthy fast food for teenagers, and they are just stuffing themselves."*[92]

In another study, perch, still in their larval state, were shown not only to take in plastics but to also prefer them to their real food. Larval perch with access to microplastic particles ate only the plastics, ignoring their natural food source of plankton.

> *"This is the first time an animal has been found to preferentially feed on plastic particles, and is cause for concern," said Peter Eklöv, co-author of the study. "Larvae exposed to microplastic particles during development also displayed changed behaviours and were much less active than fish that had been reared in water that contained no microplastic particles."*[93]

A 2017 study published in the journal *Marine Pollution Bulletin* shows that corals are also gobbling up plastics.[94] Corals, which are a sightless symbiotic animal and plant organism, find something about plastics appealing enough that they want to eat it. This is a threat to corals because like other animals, corals can't digest plastic. The eaten plastic can lead to intestinal blockages which create a false sense of fullness, impacting the health of the corals.

Some insects appear to be consuming microplastics from their environment as well. Research published in 2018 showed that mosquitoes that ate microplastics as mosquito larva when they were developing in their aquatic environment still contained some of that plastic as they became airborne adults.[95] Later as they are eaten by spiders, bats, birds and other creatures they could be dispersing those plastic bits throughout the food chain. Other winged insects have similar life cycles making them likely to be likely ways that microplastics will spread throughout the food web. Other work has already shown that mayfly and caddisfly larvae also contain microplastics.[96]

Sources of environmental and aquatic plastic contamination have expanded as more products use plastics. Products like wet wipes, marketed as flushable, clog up sewer systems, costing billions of dollars in worldwide maintenance. Because they don't biodegrade quickly, they can end up among all of the accumulating refuse on beaches.[97] These wet wipes are also made from plastics, which once flushed, break apart into microplastics and add to the world's plastic burden.[98]

Synthetic rubber, which is a variant of plastic, makes up about 60% of the rubber used in car tires. As tires wear down they emit small particles of dust into the air landing on adjoining surfaces, with an unknown amount carried out to the sea.[99] The total amount of microplastics generated from the wear of automotive tires in the EU alone is estimated at 503,586 metric tons (555,000 tons) per year or over 4,300 blue whales' worth.[100] Microplastics from tires and roads were found to make up 89% of the ultra-fine particles found in the air around busy motorways.[101]

Another major source of plastic pollution are nurdles. Nurdles are tiny pellets of plastic resin that manufacturers use to create plastic packaging and products. Billions of them are lost every year, ending up in waterways and are the second-largest source of microplastic pollution in water, after the amount generated from vehicle tires.[102] A 2018 study estimated that between 3 and 36 million pellets may escape every year from just one small industrial area in Sweden, and when smaller particles were considered the quantity released is a hundred times greater.[103]

Synthetic textiles, such as polyester and acrylic, also slowly break down while washing and drying clothes. A Plymouth University study showed that more than 700,000 microscopic fibers could be released into waste water during each use of a domestic washing machine. Many of these are likely to pass through sewage treatment and into the environment.[104] Up to 40% of these microfibers pass through wastewater treatment plants and end up in rivers, lakes and oceans. These microfibers are infiltrating the environment on a massive scale, with 85% of debris on shorelines around the world composed of this waste.[105]

As plastics break down into smaller pieces they may become the least understood area of marine litter, but potentially also the most hazardous – nanoplastics. Nanoplastics are considered to be plastics less than 100 nanometers (nm), or about the size of a typical virus such as the influenza A virus.[106] These ultra-small plastics could enter living cells causing inflammation and possible disruption of cellular functions.[107] Rachel Hurley from the University of Manchester noted:

> *"It is the really small stuff we get worried about, as they can get through the membranes in the gut and in the bloodstream – that is the real fear."*[108]

Studies have shown that these particles can be transported through the aquatic food chain via algae into fish, affecting lipid metabolism and fish behavior.[109] A recent study found that these nano-sized particles cross the blood-brain barrier accumulating inside fish brains, creating behavioral disorders through what researches believe is brain damage.[110] The study also found that animal plankton died when exposed to these nanoparticles, while larger plastic particles did not appear to affect them. According to Tommy Cedervall, a chemistry researcher at Lund University:

> *"It is important to study how plastics affect ecosystems and that nanoplastic particles likely have a more dangerous impact on aquatic ecosystems than larger pieces of plastics."*

Breakdown of plastics into nanoplastics may actually take a long time on the order of decades or centuries. However, the direct use of nanoparticles in cosmetics, detergents, food, dental and other commercial products is rapidly increasing despite very little knowledge of their effect on organism metabolism. One product, 3D printers, has been found to emit 200 billion ultra-fine particles (UFP) per minute, having potentially serious health consequences.

> *Inhaling UFPs is potentially harmful, as the particles 'deposit efficiently in both the pulmonary and alveolar regions of the lung, as well as in head airways.' The particles could also enter the brain through the olfactory nerve. Symptoms of UFP inhalation include shortness of breath, stroke, cardiac arrest and even death.*[111]

These nano-sized products will easily bypass any sewage treatment system, with these potentially very powerful particles ending up in freshwater and marine habitats. All sizes of plastics and their toxins will continue to accumulate in the environment and infiltrate the food chain, inevitably impacting human populations. Furthermore, if the magnitude of adverse effects to wildlife is severe enough, such as population-level declines, world food security could be impacted. Heidi Taylor, director of the marine debris organization Tangaroa Blue, recently noted that:

> *"This is the next climate change, and nobody's thinking that it's going to be as bad as it is. If we start looking at communities like the islands here, that rely so heavily on seafood, and that [seafood] is contaminated by plastics and chemicals that are in the ocean, this is going to be not an issue about saving turtles, this is going to be a human health issue, and that will be a game changer."*[112]

Although the plastic garbage patches, and in general marine debris, are not precisely quantifiable in all of their aspects, they are a symptom of a root problem which is plastic end-of-life use. The microplastic endgame is not the ocean garbage patches, but ultimately it is the interaction with the entire ocean ecosystem. Los Angeles captain Charles Moore, an environmental advocate credited with bringing attention to the *Great Pacific Garbage Patch*, noted that:

> *"The ocean is like a plastic soup, bulked up with the croutons of these larger items. It's like a toilet bowl that swirls but doesn't flush."*[113]

With global plastic production doubling every 11 years, during those 11 years people will make as much plastic as has been made since plastic was invented.[114] A 2017 *Ellen MacArthur Foundation* report shows that by 2050 plastics will consume 20% of all oil production, which is up from 5% today. One out of every five barrels of oil will not be to fuel our machines, but to make plastic. The report states that at least 8 million metric tons enter the oceans each year, and if action is not taken by 2050, there will be more plastic in the ocean than there are fish weighing 850 million metric tons (937 million tons)[115] or equal to over 2,500 Empire State Buildings.

> *Each year, at least 8 million tonnes of plastics leak into the ocean — which is equivalent to dumping the contents of one garbage truck into the ocean every minute. If no action is taken,*

> *this is expected to increase to two per minute by 2030 and four per minute by 2050. Estimates suggest that plastic packaging represents the major share of this leakage. In a business-as-usual scenario, the ocean is expected to contain 1 tonne of plastic for every 3 tonnes of fish by 2025, and by 2050, more plastics than fish (by weight).*[116]

We are facing an ever swelling tsunami of plastic waste that is difficult to imagine. Measurements from the most contaminated regions of the world's oceans show that the mass of plastics already exceeds that of plankton sixfold.[117] The potential for biomagnification of plastic particulates in the environment is of major concern for life all the way up on the food chain, biosecurity and ultimately human health. Dr Lisa Emelia Svensson, the director for Ocean at the UN Environment, said plastics are "ruining the ecosystem of the ocean" and are nothing short of a "planetary crisis."[118] Erik Solheim, the head of the UN's environment programme, stated that "we're facing an ocean Armageddon."[119]

A 20-foot long shipping container has a volume of 33.2 cubic meters (42.3 cubic yards)

For decades the United States and other industrialized countries have counted plastic waste as "recycled" if it is exported. While this avoids disposal costs and local environmental impacts, this waste problem is often shifted to countries with poor waste management.[120] In 2018, the United States sent 157,000 twenty foot-long shipping containers (430 per day) to such countries. This equals 5.2 million cubic meters (6.6 million cubic yards) or enough to fill over 2,000 Olympic-sized swimming pools.[121] By exporting plastics to countries that are ill-equipped to manage it, helps creates a comfortable illusion that predominantly Asian countries are to blame for the world's ocean plastic pollution. While this plastic pollution sleight of hand may make citizens and businesses in the Western world more comfortable with their plastic addiction, the end result is that increasing plastic disaster is still impacting the entire world.

Despite numerous laws, regulations, and cleanup efforts, plastic-dominated marine debris appears to be ever expanding, and hence so is the magnitude of the resulting problems. This plastic load of pollution not only reaches our oceans, but a large portion of this debris ends up on or buried in the sea floor. The potential is there for an unseen pervasive impact on deep-marine ecosystems.

The looming plastic catastrophe is something we need to tackle in a global and comprehensive way. Even if 100% of plastics in the Western world were truly recycled, the amount of plastics flooding the oceans from the developing world would still be overwhelming. This means working together as one human community to solve this massive mismanagement of waste across the planet. What is needed is a global plan to properly collect trash, recycle whatever can be and keep it from inundating the environment.

With the sea covering over 73% of our world, it is not physically practical to remove all the existing plastic debris, and with more than 90% of plastics in the ocean being less than 10 millimeters long[122] it really becomes an impossible task. Instead, we must find ways to change our continuing impact, because we can't significantly alter the enormous damage that has already been done. We must greatly decrease the use of plastics, especially the single-use type, which is nearly half of all plastics manufactured today. We must also conceptualize better processes to intercept and capture all plastics before they infiltrate the marine environment. If we don't take action, the problems will

persist, continue to escalate and become increasingly insurmountable, with only disastrous consequences for life on this planet.

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This is one chapter from an upcoming book – Moving Back from Midnight – A World in Peril.

If you have feedback or you would like to help with working on this book in any way please contact us at movingbackfrommidnight@gmail.com. Our planet is under major threats and it will take all of us taking action to reverse course and make it a sustainable world.

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