# 6 Pollution of the oceans

> Whether deliberately discharged or unintentionally introduced, plastic waste, pharmaceuticals, toxic heavy metals, insecticides and other chemicals have found their way to every corner of the oceans. The consequences are catastrophic and often lethal, especially for marine organisms. The only good news is that international prohibitions of some pollutants are beginning to have an effect. Without radical changes in industry and commerce, however, the pollution crisis in the oceans cannot be overcome.

# A problem of immense scale

**> The United Nations has estimated that humankind discharges around 400 million tonnes of pollutants into the sea annually. Evidence of this persistent pollution can now be found in all regions of the world's oceans – on remote islands, in the polar regions and in the deepest ocean trenches. Substances that are concentrated in the food chain are especially harmful because these pose a real danger to marine organisms as well as to people.**

## Contamination everywhere

Just like water and carbon, most natural substances move in giant cycles around the planet. Sometimes they are carried by flowing water and sometimes by the wind. In other cases, living organisms pick them up and transport them from one location to another. Geological processes may also convey previously deposited material back to the surface after thousands of years. The fact that materials are carried from the land into the sea is therefore just a part of the natural scheme. But since people have inhabited the Earth and have built cities, established global industries, practised intensive mining and agriculture and employed an estimated 40,000 to 60,000 different chemicals worldwide, the input of substances and materials into the world ocean has increased massively.

The terms "pollutant" or "environmentally hazardous material" refer to all substances and compounds that themselves or whose products of decay are capable of altering the properties of water, soil, air, climate, animals, plants or microorganisms in such a way as to pose an immediate or long-term risk to the environment. These criteria are fulfilled by many substances now found in the environment. In their current *Global Environment Outlook (GEO-6)*, experts of the United Nations Environment Programme (UNEP) concluded that humankind has never before lived in a world as contaminated with pollutants as it does today.

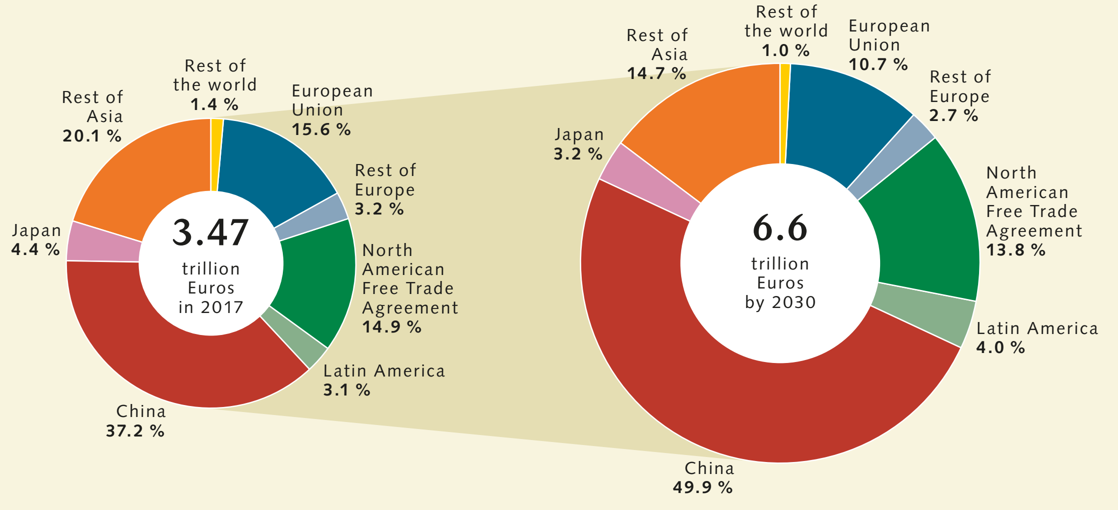
Humans themselves are responsible for this. Every year up to 400 million tonnes of pollutants are still being discharged into lakes, rivers and seas. These include thousands of chemicals, nutrients, plastics, toxic heavy metals, pharmaceutical substances, cosmetic products, pathogens and many more substances that have practical uses for humans but can cause harm when released into the environment. Around 80 per cent of these pollutants originate from sources on land. The remaining input is generated by fisheries, marine shipping, drilling platforms and aquaculture, even though the disposal of harmful waste and other substances at sea, with very few exceptions, is prohibited by the London Convention of 1972 and its supplement, the London Protocol of 1996.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) now lists pollution as the fourth-strongest driver of species extinction in the oceans. The only factors that are more detrimental are climate change, direct forms of exploitation like overfishing, and fundamental changes in usage of the seas. The latter include, for example, the destruction of natural coastal systems and river deltas, the expansion of marine aquaculture and ruinous bottom-net fishing.

UNEP experts refer to the high levels of contamination on land and in the sea as a global pollution crisis that is depriving humanity of its own livelihood. In the long run, only nature in a healthy state will be able to provide people with sufficient food, drinking water and other vital services. Globally, three times more people are dying today from the effects of environmental pollution than from the deadly diseases AIDS, malaria and tuberculosis combined.

The steady input of pollutants into the oceans is a direct result of the increasing production and use of these substances on land. Every year more fertilizer is being produced around the world, and more crop-protection products (pesticides) are being applied to increase the harvests and provide the Earth's growing population with food, plant-based fibre, animal feed and biofuels. From 2002 to 2018, for example, the amounts of crop-protection products used per hectare of farm land rose by 30 per cent. During the same period, farmers around the world increased their use of artificial fertilizers by 13 to 56 per cent in order to enrich their lands with nitrogen, phosphorus and potassium.

**Projected growth in worldwide chemical sales (excluding pharmaceuticals), 2017 to 2030**




**6.1 > Growth market: More and more chemicals are being sold worldwide. According to the United Nations, turnover in this sector will grow to USD 6.6 trillion by the year 2030. By that time, around 70 per cent of all chemical sales will be carried out in Asia.**

### The London Convention and its Protocol

The London Convention of 1972 was one of the first treaties in international law to make marine conservation an international obligation. It was amended by the London Protocol in 1996, which is applicable to those states that had previously agreed to the Convention. Both treaties were developed to regulate the discharge of hazardous wastes and other substances into the ocean. As of January 2021, however, only 87 states had acceded to the Convention and only 53 to the Protocol, which means that coverage is less than universal for both of them.

Nevertheless, the London Convention sets internationally binding standards for marine conservation, in part because it is reinforced by the UN Convention on the Law of the Sea, the charter for the oceans that is recognized by almost all countries. The UN Convention on the Law of the Sea indirectly holds the standards of the London Convention and potentially also those of the Protocol to be applicable to all states, including those that have not signed the treaties.

The London Protocol came into force in 2006 and generally prohibits the discharge of waste into the sea. Exceptions to the ban include dredged material, sewage sludge, fish waste, derelict ships and drilling platforms, as well as natural organic and geological material.

Household products, furniture and electronic products are being manufactured with increasing amounts of plastic, and thus contain a large variety of environmentally hazardous chemicals. The wealthier people are, the greater their perceived needs become and the more they consume. However, our consumption-oriented lifestyle is producing mountains of waste, while people in the industrialized nations in particular are consuming more and more medicines to treat common ailments such as diabetes or headaches and back pain. And as more hazardous chemicals are bought and sold, the risk of accidents during their transportation increases, often resulting in severe environmental damage – both on land and at sea.

The great variety of applications for the known pollutants clearly illustrates that only a portion of the chemicals known today to be hazardous were initially developed with the intent that they be toxic, such as pesticides. Many were intended to fulfil completely different purposes and be used primarily for the well-being of people. The harmful effects of these substances were often not realized until they appeared in increasing amounts in the rivers, lakes and oceans and scientists began to recognize their connections with diseases in aquatic organisms.

The use of these chemicals is expected to continue to increase, even though for many of them the potential danger to the environment is completely unknown. To make matters worse, the prohibition of especially hazardous substances is never even considered until after the first catastrophic environmental impacts are observed. But no one can presently really say how much of these substances will have already reached the lakes, rivers and oceans by then, and what long-term consequences they will have. It is a known fact, however, that winds and ocean currents are distributing the pollutants to every corner of the world's oceans, and that they are thus reaching the most remote and inaccessible regions.

**Chemicals of special concern**
Chemicals have a very large range of physical and chemical (physicochemical) properties and can have a wide variety of effects on living organisms. Substances that cannot be naturally degraded (longevity, persistence), those that are enriched in organisms (bioaccumulation) and poisonous substances (toxicity) are particularly hazardous. Substances with hormone-like effects, called endocrine disruptors, also fall into the category of "special concern" because of their problematic properties, and are thus considered to be highly hazardous.

A few years ago, while studying deep-sea amphipods in the Mariana Trench (the deepest ocean trench in the world) for environmental pollutants, scientists found that the animals there contained 50 times more persistent organic pollutants (POPs) than shrimp taken from the estuary of one of China's dirtiest rivers. Toxicity levels similar to those in the Mariana Trench amphipods have only been found in animals from Japan's Suruga Bay, a highly industrialized coastal region where chemicals with organochlorine compounds (chlorinated hydrocarbons) were previously used on a large scale. Many of these chemicals, primarily used in pesticides or flame retardants, have now been banned.

## Pollutant accumulation in the food chain

Scientists have not been able to provide a clear explanation for the high contamination observed in the deep-sea amphipods from the Mariana Trench. But the bioaccumulation of toxic substances could play a part. Bioaccumulation is defined as the uptake of a substance from the environment and its subsequent enrichment in an organism. Not only do the marine organisms ingest the chemicals with their food, the substances can also enter the organisms through the skin or gills and then be deposited in their fatty tissue. Accumulation is facilitated by the fact that most of the harmful substances do not dissolve in water at all, but are readily soluble in fats and oils. Fats, in turn, are important building blocks for plant and animal cells. Furthermore, marine organisms form fatty tissue as an energy reserve in times of scarce food supply. But with the bioaccumulation of pollutants, fat reserves like the blubber in whales and seals can become veritable repositories of poisons.

The degree of bioaccumulation is usually reported as the ratio of the chemical accumulated in the organism relative to its concentration in the environment. According to the German Federal Environment Agency, accumulation factors of up to 100,000 have been observed for some highly accumulating chemicals. This means that the animals take up these chemicals from their surroundings and can enrich them in their bodies up to 100,000 times the concentration present in the environment.

The consequences for the animals are many and they vary from one species to another. The numerous toxic substances in the sea can:

- trigger diseases like cancer,
- lead to deformities,
- cause hormonal changes (for example, female fish form male genitalia) that affect the reproduction of many species,
- damage the genetic make-up of an animal or cause genetic mutations,
- cause behavioural changes,
- often lead to the death of the contaminated marine organism.

Predatory animals at the top of the marine food chain are often severely impacted by this. These include sharks, toothed whales, seals and seabirds – and humans when we eat fish or seafood that is heavily contaminated with environmental pollutants. This high risk to the predator is due to the fact that the poisons are passed up through the food chain. The heavily contaminated amphipods are eaten by a small fish, which then ends up in the stomach of a predator fish that is eventually eaten by a killer whale. The more often this sequence, known as biomagnification,

**6.2 > The deep-sea amphipod *Eurythenes plasticus* carries the word "plastic" in its name. The reason is that when biologists first discovered the species in the Mariana Trench, they found fibres made of polyethylene terephthalate (PET) inside the intestines of one animal, a kind of plastic that is present, for example, in disposable bottles and in sports clothing.**

is repeated, the more the body of the killer whale is enriched in toxic substances and damaged by them.

European scientists observed record rates of poisoning several years ago when they studied tissue samples and examined reports on the cause of death of more than 1000 striped dolphins *(Stenella coeruleoalba)*, bottlenose dolphins *(Tursiops truncatus)* and killer whales *(Orcinus orca)*. They were addressing the question of the degree of contamination by pollutants such as chlorinated hydrocarbons in the mostly dead animals that were washed ashore (carcasses from 1990 to 2012). This group of substances includes some pesticides (such as lindane and DDT) and polychlorinated biphenyls (industrial chemicals). The recorded poisoning rates exceeded all previously measured levels for marine mammals, although the production and use of the toxic substances involved had been banned in the USA in 1979, in Great Britain in 1981 and in the Mediterranean countries in 1987.

The scientists reported that the extremely high levels of poisons in the animals were a primary reason why many of them were sick and infested with parasites. Dolphins and killer whales from the Mediterranean were hardest hit by the poisons. This landlocked sea is a toxic hotspot that is so heavily contaminated by chlorinated hydrocarbons, mostly from the group of polychlorinated biphenyls, but also by other pollutants, that the dolphin and killer whale populations have been declining for the past 50 years. This is mainly because wale offspring has become rare due to infertility caused by the poisons.

The six females of the only remaining killer whale family existing in the Mediterranean Sea at the time of the study, for example, gave birth to only five calves during the period from 1999 to 2011 that were able to survive past the age of one year. Up to the time of the publication of the study in 2015, a single group of killer whales that were regularly sighted off the northwest coast of Scotland

6.3 > Although there are hardly any people living in the rainforest-covered region of northern Columbia, thousands of fragments of plastic wash ashore with every wave surge and pollute the remote coastal strip.



and in western Ireland produced even fewer offspring. Over the 19 years that the scientists had observed these whales up to that time, the animals did not have a single young animal with them, although the group comprised both male and female individuals.

## Pollutants in the sea

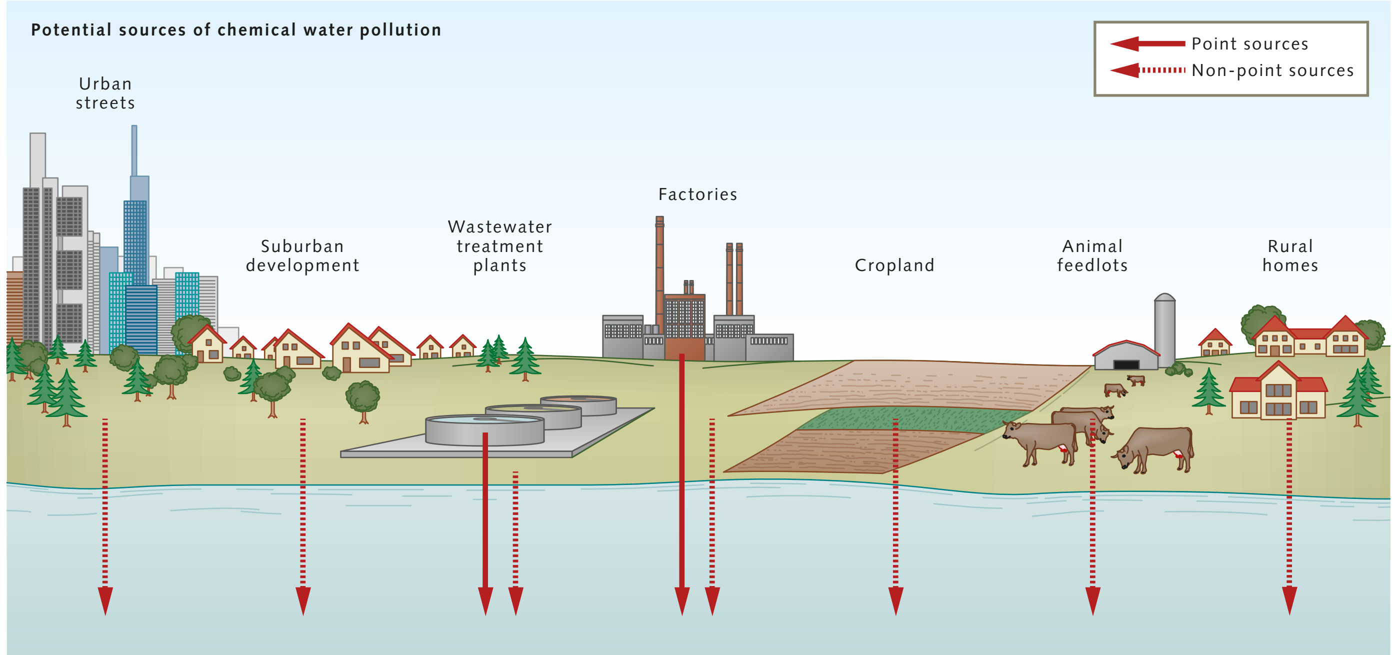
In eight of ten cases, marine pollution begins on land. Only occasionally is it possible to trace it back to a single source. These point sources include chemical plants or mines that discharge waste or effluent into rivers or directly into the sea, but also ships that discharge their garbage before entering a port. Point sources also include wastewater treatment plants that collect all of the wastewater from a region, treat it to some degree and then discharge it into a river or directly into the sea. In addition, there are still many communities that dispose of their wastewater without treating it, according to the old maxim: the best way to get rid of filth and waste is to dump it into the sea.

But much more often, marine contamination comes from more diffuse sources. There are many offenders and, as a rule, they are not easily identified. Furthermore, the pollutants do not always enter the sea through direct discharge, but may also be transported through the air or by rainwater.

On the west coast of the USA, scientists have recently discovered that a chemical additive in car tyres meant to protect them from degradation by ozone has caused the death of up to 90 per cent of the population of coho salmon *(Oncorhynchus kisutch)* in rivers after a strong rainfall. The chemical is present in the fine particulates from tyre wear that are produced when cars drive over asphalt. When it comes into contact with ozone, its chemical structure changes to produce a poison. The particles are then washed into the rivers during the next rainfall; the poison escapes from the tyre rubber and becomes fatal for the coho salmon.

Once they have reached the sea, environmental pollutants act in highly diverse ways. Water-insoluble substances, such as polychlorinated biphenyls, adhere quickly to the tiny remains of animals and plants and sink with them to the seabed, provided the particles are not broken down by microbes or eaten by animals on their way to the bottom. Other substances, such as the highly toxic organic

6.4 > Eighty per cent of the pollutants in the ocean originate from onshore sources. Experts distinguish between point sources and non-point sources. The former category includes factories or water treatment plants that discharge their effluent directly into the sea. The latter refers to those sources that discharge pollutants into the ocean by more indirect pathways.



tin compounds (including tributyltin, TBT), which have long been used in marine paints, evaporate easily and can thus enter the atmosphere when water evaporates at the sea surface. They are carried away by the wind and eventually condense with the water vapour and fall as rain somewhere else. They are therefore only redistributed and not decomposed.

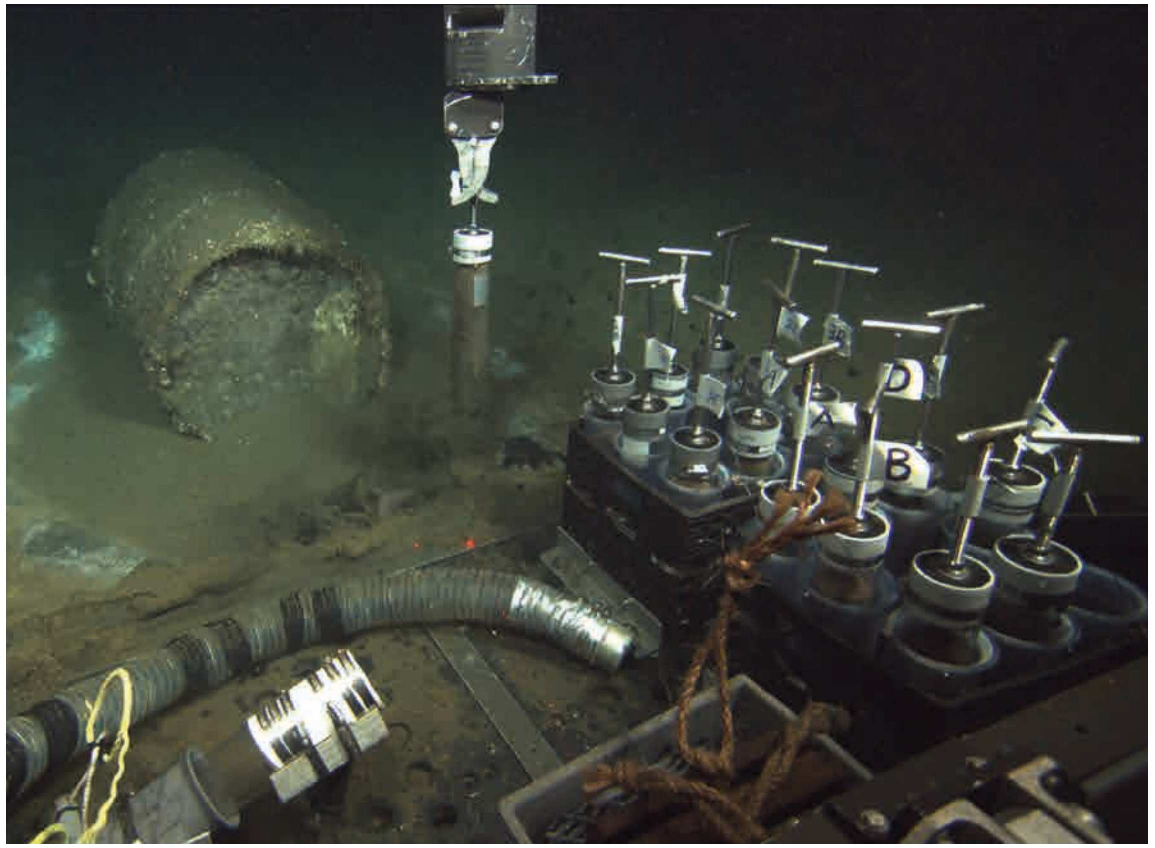
This situation, along with the fact that marine currents can distribute pollutants around the entire globe, makes their input to the sea an international issue that crosses all borders. The solutions thus require international cooperation and the use of joint and coordinated measures.

The most relevant groups of pollutants in the sea under scrutiny by environmental scientists include:

- polychlorinated biphenyls (PCBs), pesticides and other groups of substances that fall into the larger category of persistent organic pollutants (POPs),
- pharmaceuticals (medicines) as well as hormones and hormone-like substances,
- heavy metals,
- polycyclic aromatic hydrocarbons (PAHs),
- per- and polyfluorinated alkylated substances (PFAS),
- radioactive materials,
- plastic waste.

## Persistent organic pollutants

The collective term “persistent organic pollutants” (POPs) encompasses a large group of organic chemicals that can contain halogens such as fluorine, chlorine, bromine, iodine or astatine. Because of their chemical compositions they are not readily degraded in nature and are thus very long-lived. POPs can thus be transported over long distances. They accumulate in suspended organic matter in the water and in the fatty tissues of organisms, and they are toxic to humans and animals. Even very small amounts of these contaminants can cause cancer. They damage the central nervous systems of living organisms, weaken their immune systems and cause problems with reproduction. The development of children who were exposed to POPs at an earlier age is signifi-cantly impaired compared to their peers who were unexposed.



6.5 > From 1930 to 1972, in the marine region between the US metropolis of Los Angeles and Santa Catalina Island, industrial waste was dumped on a large scale at water depths of up to 900 metres, including many containers filled with the insecticide DDT (dichlorodiphenyltrichloroethane). Because of this, the sea floor as well as all the higher life forms in this region now contain dangerously high concentrations of DDT.

Experts distinguish between two kinds of persistent organic pollutant. The first comprises synthetically produced POPs that were used in the past for a great variety of purposes and still have many applications today. These toxic chemicals were sprayed as plant protectants, used as flame retardants, refrigerants and solvents, or in the production of varnishes, paints, adhesives, sealants, plastics and insulation (such as polystyrene insulation material). The second category of POPs comprises those that were unintentionally produced and includes the by-products of various combustion processes.

Although the devastating effects of this large group of pollutants has been known since the 1960s, and the production of some POPs was already prohibited at the national level by the 1980s, it was not until 1997 that negotiations toward an international agreement to limit the production and application of these substances began. The Stockholm Convention was finally adopted in May 2001 and came into force on 17 May 2004. To date 184 countries have acceded to the agreement.

The text of the convention lists three groups of pollutants:

- POPs that should be systematically eliminated;
- POPs whose production and use should be restricted;
- POPs whose unintentional generation as by-products should be reduced.

Waste containing or contaminated with POPs, according to the convention, must be disposed of in a way that destroys the POPs or irreversibly transforms them so that they lose their hazardous properties.

When the convention was adopted in 2001, there were only twelve POPs on the lists, which were known as the “dirty dozen”. These included:

- pesticides (herbicides and insecticides) such as aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex and toxaphene;
- industrial chemicals like hexachlorobenzene and polychlorinated biphenyls (PCBs); and
- by-products such as dioxins and furans.

As a part of the convention process, a group of experts known as the Review Committee was formed which meets annually to compile and discuss research findings on the effects of POPs that are still unlisted. If these chemicals are deemed to be of special concern – i.e., particularly hazardous – the Review Committee commissions risk assessments and subsequently proposes their listing to the member states of the convention along with specific recommendations for their elimination or restriction.

Since the Stockholm Convention first came into force, bans have been adopted for 19 additional pollutant groups. The focus of the Review Committee has changed significantly over the past two decades. In the early years of its existence the committee was primarily focussed on pesticides that were already banned by many countries, but it is now more involved in addressing much newer, complex industrial chemicals. Many of these are still being used in large quantities and are thus economically significant for a number of countries. The task is made more difficult by the fact that these substances have been in use for a relatively short time and it is virtually impossible to compile data and build knowledge about their possible dispersal pathways and environmental impacts. An accurate understanding of their potential harmful effects usually only becomes possible when it is too late, after excessive quantities of the chemicals have already been discharged into the oceans.

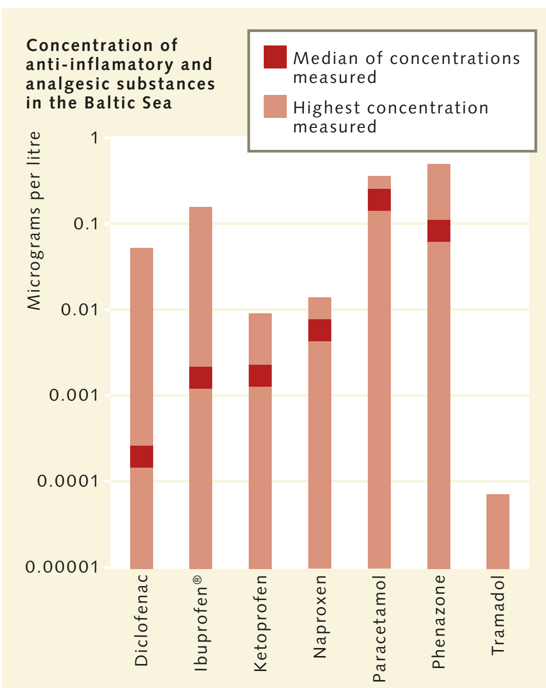
Nevertheless, international bans are having the desired effect. The concentrations of POPs that have been banned by the Stockholm Convention and by national and

**Chlorinated hydrocarbons**
The mass production of chlorinated hydrocarbons (CHCs) began in 1929 and peaked in the 1960s and 1970s. Around 97 per cent of the CHCs produced were applied in the northern hemisphere, which is why the seas on this half of the globe are especially heavily polluted with these persistent environmental poisons. By the end of the 1990s it was estimated that six to seven per cent of the total production up to that time was already stored in the seabed.

transnational agreements are gradually decreasing in the oceans.

## Pharmaceuticals (medicinal products)

Pharmaceuticals, or medicinal products, are man-made chemicals developed for a specific purpose: targeting cells, influencing an organism's hormone levels or regulating the uptake and processing of nutrients, for example. In some instances, pharmaceuticals even regulate intercellular communication. In order to maximize their therapeutic effect, pharmaceutical products that are administered orally must reach the intestine, where they are absorbed into the bloodstream. Before that, however, they must pass unscathed through the highly acidic, and hence destructive, stomach environment. Most active pharmaceutical ingredients (APIs) are therefore designed to be highly stable and degrade very slowly, or not at all.




**6.6 > Common analgesics such as diclofenac, ibuprofen and paracetamol are just some of the pharmaceuticals that are excreted by humans into wastewater and then enter the rivers and finally, in this instance, the Baltic Sea.**

When these highly stable active substances enter the environment, they are referred to as environmentally persistent pharmaceutical pollutants (EPPPs) – and they pose a growing threat. The antibacterial effect of antibiotics, for example, can cause bacteria and other microbes to develop resistance to these substances, which means that these antibiotics can no longer be used to treat bacterial infections. According to the United Nations, the number of antibiotic-resistant bacteria is increasing, with antibiotic resistance now one of the greatest threats to human health.

Pharmaceuticals enter the sea by a variety of routes. Some are direct inputs from pharmaceutical companies, hospitals, hotels and restaurants discharging their untreated industrial waste or wastewater contaminated with active substances and disinfectants into rivers and sea. Another source is feed containing pharmaceuticals, which is distributed in cages in marine aquaculture. However, pharmaceuticals also leak into the environment when humans or animals take medication to treat a condition or disease and then excrete the active substances in their urine or faeces. With livestock, the active substances may be present but undetected in manure or slurry, which is then spread on fields, only to leach into nearby watercourses when it rains. And while human excrement is normally flushed down the toilet, the number of sewage treatment plants that filter out active pharmaceutical substances is still far too low. More than 80 per cent of the world's wastewater is still discharged into the environment without any treatment, making animal and human urine and faeces the main source of pharmaceutical residues in rivers and seas.

According to the United Nations Environment Programme (UNEP), approximately 4000 active pharmaceutical ingredients are administered worldwide in therapeutic and veterinary drugs, including prescription medicines and over-the-counter products. These active substances are removed from wastewater in sewage treatment plants with an efficiency of 20 to 80 per cent. The rest enters the rivers and seas. As a rough estimate, around 1800 tonnes of pharmaceutical residues enter the environment annually from sewage treatment plants in the Baltic Sea region alone. And year after year, China's longest river, the Yangtze, carries the sewage of more than 400 million people, containing some 152 tonnes of pharmaceuticals, out to sea.

Water pollution by pharmaceuticals is now present on such a scale that scientists are able to use water samples to draw firm conclusions about a nation's health. In a large-scale study conducted in the USA in 2014 to 2017, for example, researchers detected a total of 111 pharmaceutical compounds in headwater streams; some water samples contained mixtures of up to 60 different active pharmaceutical ingredients. The most common substances identified by the scientists were:

- nicotine, the stimulant found in tobacco;
- metformin, the diabetes and cancer drug, for which around 81 million prescriptions were issued in the USA in 2016 alone. It is excreted in human urine in a more or less pure form;
- caffeine, the stimulant contained in coffee, energy drinks, etc.;
- lidocaine, an anaesthetic.

The researchers also detected pharmaceutical mood enhancers (antidepressants) and anti-histamines; indeed, the latter were identified in seasonally varying concentrations (in step with the risk of hay fever being particularly high in spring).

Similar results were produced by a large-scale study on pharmaceutical pollution in the Baltic Sea, published in 2017. In this instance, however, analgesics and anti-inflammatories, such as paracetamol, ibuprofen and diclofenac, and cardiovascular and central nervous system agents topped the list of most frequently detected substances. In total, the researchers detected 167 pharmaceutical substances in the marine environment of the Baltic Sea region. Again, the main sources identified by the researchers were human and animal urine and faeces, whose pharmaceutical contents were not adequately removed during sewage treatment processes. Out of 118 pharmaceuticals whose filtering out was assessed by the researchers at various treatment plants, only nine were removed from wastewater with an efficiency over 95 per cent and nearly half of the compounds were removed only partially with an efficiency of less than 50 per cent.

Some medicinal products, such as the anti-inflammatory diclofenac (the active ingredient in Voltaren and other analgesics), are bio- and photodegradable (i.e. they decompose when exposed to light). These pharmaceuticals are not thought to bioaccumulate in living organisms. When present in high concentrations in water bodies, they are certainly harmful, however. Diclofenac, for example, is reported to cause damage in the internal organs of fish. Laboratory studies have shown that the diabetes drug metformin affects behaviour in the Siamese fighting fish *(Betta splendens)* and disrupts growth in the Japanese rice fish *(Oryzias latipes)*. Even in low concentrations, hormones such as those contained in the contraceptive pill (e.g. 17-alpha-ethinyl estradiol) cause transgenderism in fish, threatening reproduction and leading to population decline.

Mussels appear to be particularly vulnerable to exposure to pharmaceutical residues as they are known to filter seawater in order to extract the nutrient particles that it contains. Researchers have detected the antidepressant sertraline in roughly two-thirds of the mussels collected along the coast of the US state of California, while in the Bohai Sea of China, 142 of 190 mollusc samples were found to be contaminated with antibiotics. Traces of pharmaceuticals have also been found in squid from the Central Pacific, in herring from the North Atlantic and in sharks from the Eastern Central Atlantic. These findings indicate that these active pharmaceutical substances have biomagnified in the food web.

It is extremely difficult to trace the mechanisms by which pharmaceuticals affect marine ecosystems and to attribute these effects to specific products, particularly when mixtures of drugs are present, possibly causing reciprocal amplification of their effects. Researchers have already observed such forms of mixed toxicity in phytoplankton and some freshwater organisms. The research community cannot currently provide a conclusive answer to the question of what the specific effect of drug cocktails in the marine environment may be. Research on this topic is ongoing.

As a further challenge facing scientists, many pollutants are only detectable using specific analytical methods. This means that researchers must generally decide beforehand which substances they intend to investigate. Screening studies, which involve the application of all known methods in order to ascertain which substances may be present in seawater, are extremely complex and therefore less common. Furthermore, the chemical evidence that a substance is present in seawater does not, in itself, reveal any information about its impact on marine life. That would require further analyses to study the effects on individual organisms, with scientists investigating whether tumours are present, whether there is any disruption of the endocrine system, or whether enzyme activity in living organisms has changed.

The increasing consumption of pharmaceuticals and improved measuring techniques over recent decades mean that more pharmaceuticals are now being detected in the environment. Many are present in such high concentrations that they cause harm. For that reason, experts now recognize pharmaceuticals in the environment as one of the emerging policy issues in international chemicals management.

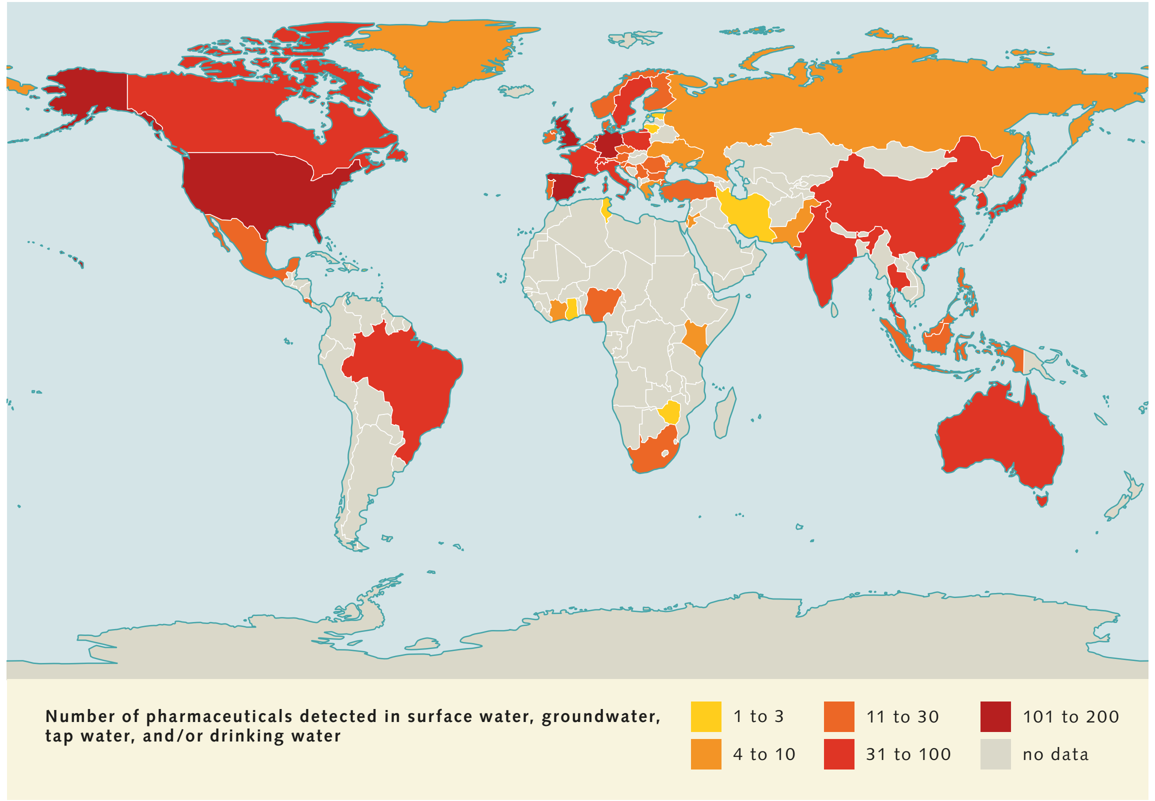
According to the definition provided by the Strategic Approach to International Chemicals Management (SAICM), pharmaceuticals in the environment are an issue which:

- affects all stages of a chemical's life cycle,
- has not yet been widely recognized,
- is inadequately managed,
- is the product of the "state of the science",
- has significant effects on human health and the environment,
- is a global problem.

SAICM was launched in 2006. It is a policy framework, non-binding under international law, which pursues a multi-stakeholder, multi-sectoral global approach, and whose overall objective is the achievement, originally by 2020, of the sound management of chemicals throughout their life cycle, from production to use and disposal. Various recommendations were adopted at a SAICM Workshop on Pharmaceuticals in the Environment, including the following:

- develop sustainable active pharmaceutical ingredients (i.e. active substances that are absorbed more efficiently in humans and animals and biodegrade more quickly, causing less damage if they enter the environment);
- run global campaigns to raise awareness of the harmful effects of pharmaceuticals in the environment, combined with information on safe disposal;
- develop well-functioning take-back and disposal systems worldwide for expired or partially used pharmaceuticals in order to curb illegal disposal;
- establish sufficiently large-scale wastewater treatment plants where none are currently available – particularly in the world's rapidly growing mega-cities, whose wastewater often contains pharmaceuticals in high concentrations;
- introduce new, highly efficient filtration technologies (Stage 4 treatment) in existing treatment plants in order to increase their purification efficiency;
- construct specialized treatment plants at point sources, such as hospitals;
- introduce strict separation of foul water and rainwater drainage systems (this avoids dilution of pharmaceutical concentrations in foul water, making it easier for treatment plants to filter out these pollutants);
- develop comprehensive monitoring systems, as well as international databases and networks for knowledge-sharing and the joint planning and implementation of protective measures.

In its Water Framework Directive (WFD), the European Union obliges Member States to assess the status of their water bodies to determine the presence of specific pollutants. In practice, however, the application of this policy requirement is proving extremely difficult in many instances, as the detection limits specified and required by the EU are extremely low; many laboratories lack the technical capacities to measure such small concentrations.




6.7 > Analyses of groundwater and surface water show that the more developed the country, the more traces of pharmaceuticals are found in its immediate environment. In Germany, Spain and the USA, as many as 200 different pharmaceuticals have been detected.

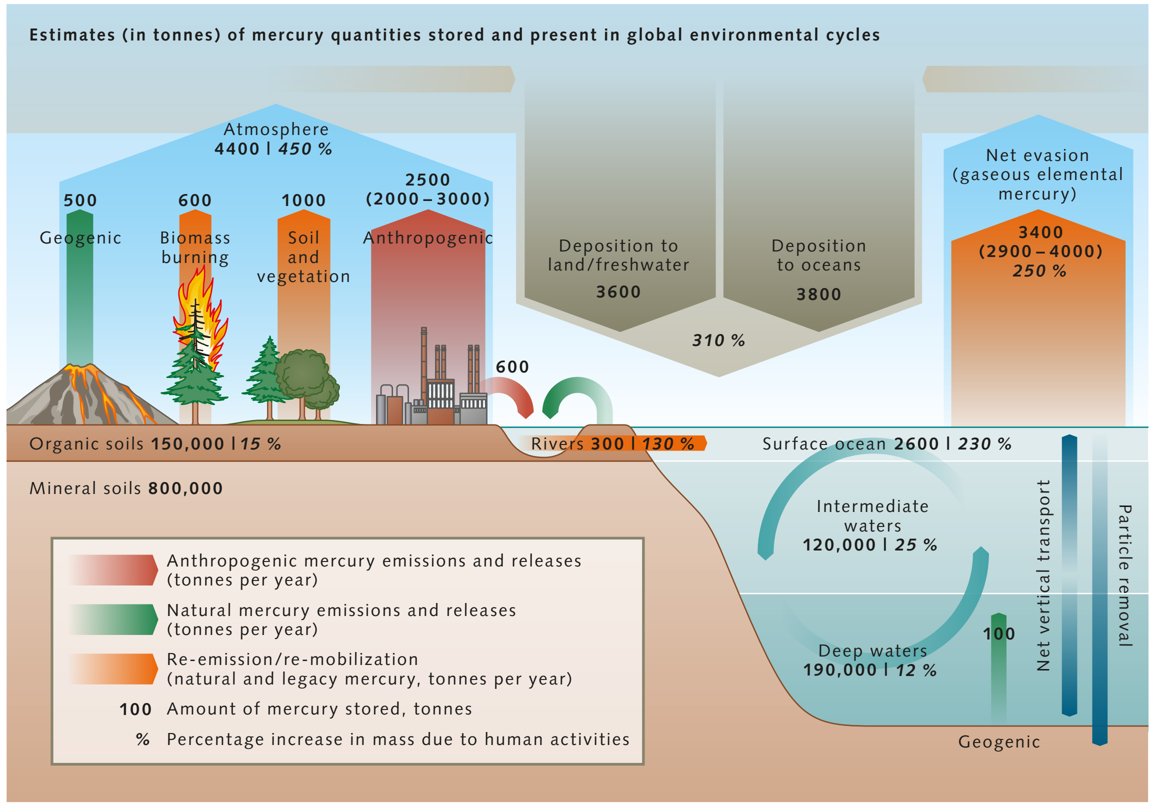
## Heavy metals

Heavy metals are naturally occurring elements that are present in the Earth's crust. Their effect is twofold. Some of them – known as trace elements – provide essential nutrients and are therefore vital for the survival of almost every living organism on Earth; examples are iron, manganese, molybdenum, copper and zinc. Other heavy metals such as lead, cadmium and mercury are toxic and harmful to human and animal health.

Toxic heavy metals enter the environment by various routes. They are utilized in mining and some industrial processes, such as plastics manufacturing, and are present in sewage sludge and plant protection products, which are applied to crops. They are assembled into batteries and various types of measuring device, and are released into the atmosphere from vehicle emissions and coal-burning. The latter has caused a 300 to 500 per cent increase in mercury concentrations in the atmosphere over the past century. These heavy metal pollutants enter the marine environment via rivers and surface runoff, or are washed out of the atmosphere in rainfall and deposited in the sea.

According to experts, approximately half of the mercury released into the atmosphere by human activity has entered the ocean. This is borne out by the findings of a study which shows that mercury levels in surface water have doubled over the last 100 years. Mercury pollution has increased by a quarter in intermediate waters and by one-tenth in deep waters. The differences, according to the researchers, reflect the time it takes for particles and seawater to travel from the surface to the various depths.

6.8 > Human activities such as mining and coal-burning have resulted in a continuous rise in mercury releases since the 16th century. From 1900 to 2000 alone, the amount of mercury in the atmosphere increased at least threefold – along with mercury depositions to land and ocean. This figure shows the sources and sinks of this toxic heavy metal, along with global amounts for 2018.




In the sea, certain species of bacteria can convert the mercury into methylmercury compounds. These metallo-organic compounds are highly toxic; they are also fat-soluble and thus able to biomagnify in the food chain. The known effects of methylmercury poisoning in humans include damage to the nervous system, a weakened immune system response, vision impairment, respiratory failure and disorders of the liver, kidneys, skin and cardiac muscles.

Marine dwellers are generally exposed to lower mercury concentrations than wildlife in lakes and rivers. Nevertheless, in recent decades, researchers have observed an increase in methylmercury levels in marine fish, notably in species from the North Atlantic and the waters off West Greenland. In fish from the marine waters off East Greenland and the European Arctic, by contrast, methylmercury levels have generally decreased. Even so, in their latest *Global Mercury Assessment*, United Nations Environment Programme (UNEP) experts conclude that mercury loads in some aquatic food webs are worryingly high and pose a risk to the health of wildlife and human populations. Climate change amplifies this risk: in the Arctic, for example, the temperature-related decline in sea ice has influenced mercury distribution and transport and, in some areas, increased mercury methylation rates, which means that more mercury is being converted into methylmercury than before.

In light of these immense risks and the global distribution of mercury in the atmosphere and the terrestrial and marine environment, the international community – after many years of negotiations – adopted a multilateral convention in 2013 whose aim is to protect the environment and human health from mercury emissions. The Convention is named after the Japanese coastal city of Minamata, where, in the 1960s, a chemical factory discharged mercury-contaminated wastewater into the sea over an extended period of time, causing this toxic substance to bioaccumulate in marine fish. The fish were then caught and consumed by coastal communities, resulting in more than 2200 cases of methylmercury poisoning. Some of the victims were unable to walk, stand or swallow due to the severity of the damage to their central nervous systems.



The Minamata Convention entered into force on 16 August 2017. It is legally binding on all parties and, to date, has been signed and ratified by 127 countries and the European Union. Among other things, parties undertake:

- to refrain from opening any new mercury mines, and to phase out mining in existing facilities;
- to reduce the mercury content of many products and industrial processes;
- to establish a monitoring system for mercury emissions to the atmosphere, land and water;
- to ensure the safe storage of mercury at all times, including management of mercury-containing devices or products that were disposed of as waste some time ago (hazardous waste).

Thus far, however, the regulations derived from the Convention have had no impact on the international markets: mercury continues to be mined and traded to a similar or increasing extent, with no decrease in production seen yet. Nevertheless, experts predict a lasting transformation of the mining and trading of mercury in the longer term as a result of the Minamata Convention.

## Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are a group of more than 100 different chemicals. They occur naturally in coal and crude oil, but are also released as a by-product from the incomplete burning of coal, oil and gas, wood, waste and other organic material. This can happen naturally in forest fires and volcanic eruptions, for example. However, most of the PAHs that are present in the environment were produced in industrial combustion processes and can thus be attributed to human activity.

Many of these hydrocarbons have carcinogenic, mutagenic and reprotoxic properties. This poses a risk, particularly in the case of PAHs which do not break down in the natural environment but can bioaccumulate in living organisms.

Most PAHs are derived from oil and are used as softeners in the manufacturing of rubber and plastic products. These pollutants are therefore present in items such as flip-flops, bicycle handlebar grips, tyres, mouse mats, toys and anti-corrosion paints. They enter the environment mainly through dust particles, to which they adhere, and through abrasion of rubber products such as tyres. The particles are then deposited on land or water surfaces or are washed into the rivers and sea by rainwater.

Large quantities of PAHs are discharged into the sea as a result of oil leaks or oil tanker accidents, often causing the collapse of local marine ecosystems. A particularly striking example is the Niger Delta in Nigeria, where transnational corporations have operated oil production facilities since 1958. According to environmental experts, around 1.5 million tonnes of oil containing 3000 to

6.9 > Aerial view of a polluted river near Port Harcourt in Nigeria. In the Niger Delta, the contamination caused by decades of oil industry operations is so severe that it will take up to 30 years to clean up and restore the environment, according to a UNEP report published in 2011.

105,000 tonnes of toxic PAHs were released into the delta until 2006, with devastating impacts on all forms of aquatic life.

In order to protect human health and the environment from the harmful effects of PAHs, the EU Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) prohibits the supplying, to consumers, of substances classified as carcinogenic, mutagenic or toxic to reproduction. Eight PAH substances fall within the scope of this provision. In order to minimize PAH inputs into the environment, this group of pollutants is governed by the rules and limit values set forth in the Protocol to the Convention on Long-Range Transboundary Air Pollution on Persistent Organic Pollutants, the EU POPs Regulation and the EU Water Framework Directive.

## Per- and polyfluorinated alkylated substances

The per- and polyfluorinated alkylated substance (PFAS) group now comprises more than 4700 chemicals which, due to their water-, grease- and dirt-repellent properties, are found in a wide variety of products, including outdoor clothing, cookware, paper and printed products, carpets, paints and fire-fighting foams. They enter the environment by various routes: during manufacturing, processing into products, subsequent use and final disposal. PFAS are dispersed by air, rivers and ocean currents, reaching remote regions of the world, and, like many other chemicals, are poorly degradable. Furthermore, some of these chemicals bioaccumulate in wildlife, plants and human tissue and are harmful to health. According to scientists, PFAS chemicals are now ubiquitous in the environment and are present in soil, in all the oceans, in the atmosphere, in flora and fauna, in human blood and even in breast milk.

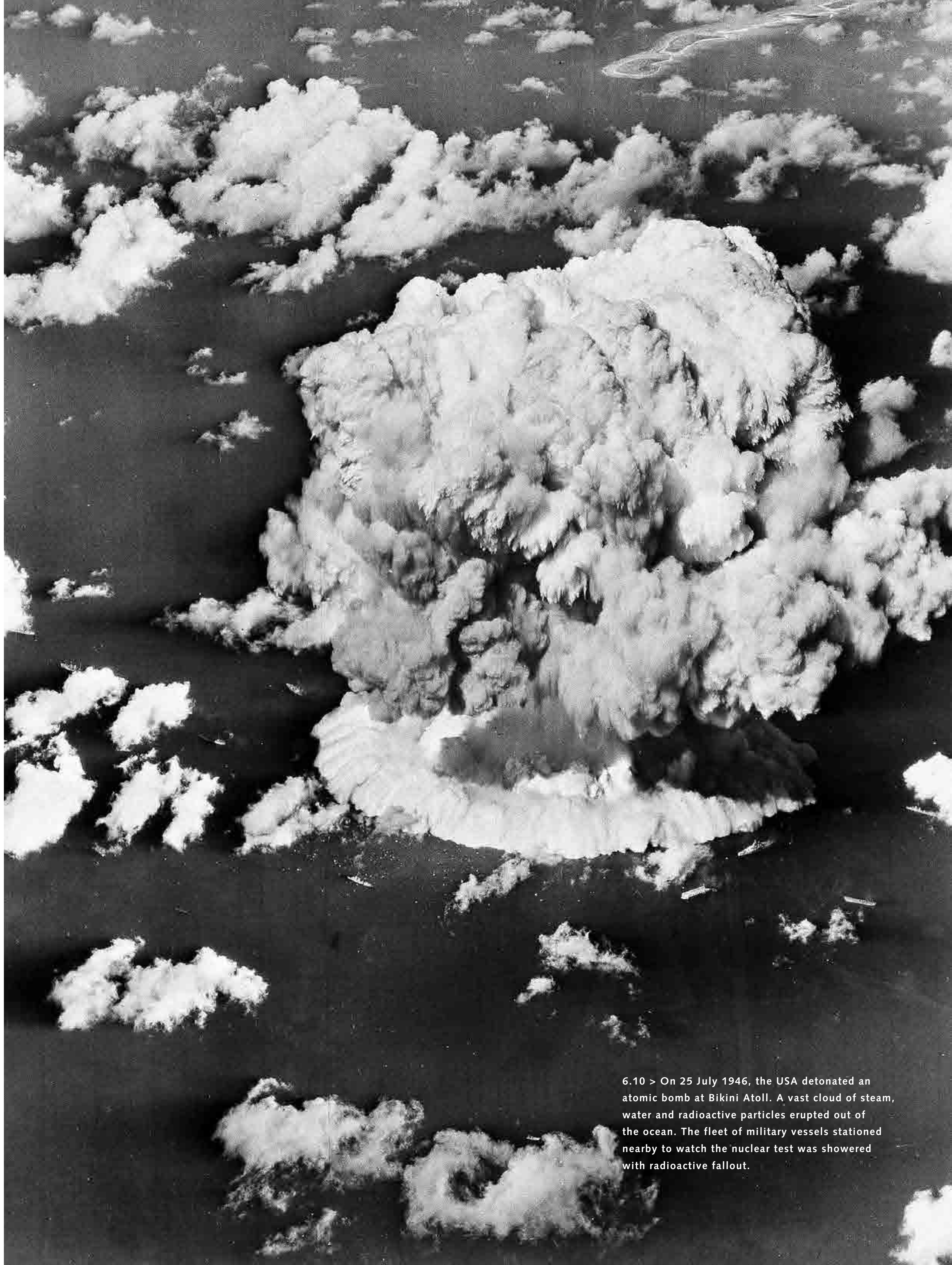
The PFAS chemicals whose names are most familiar to us have been in production and use since the 1950s. More recently, however, industry has relied mainly on new forms of these pollutants, with researchers and regulatory authorities having little to no information about their composition and environmental impacts. According to the German Environment Agency (UBA), around 40 PFAS can be detected using chemical proof procedures. However, no information is available about the precise chemical structure of most of the other chemicals in this substance group, and no analytical methods exist to detect them, making them far more difficult to regulate.

Due to their worrying properties, some PFAS chemicals already fall within the scope of the EU REACH Regulation. However, experts are calling for worldwide bans on their manufacturing and use, as well as for the development of eco-friendly alternatives. Global bans are enforceable under the Stockholm Convention, whose expert group recently added perfluorohexane sulfonic acid (PFHxS), which belongs to the PFAS group, to the list of prohibited substances. The experts also recommended that other PFAS chemicals be included in national and international monitoring programmes in order to assess whether regulatory measures are having the desired effect and PFAS contamination of the environment is decreasing.

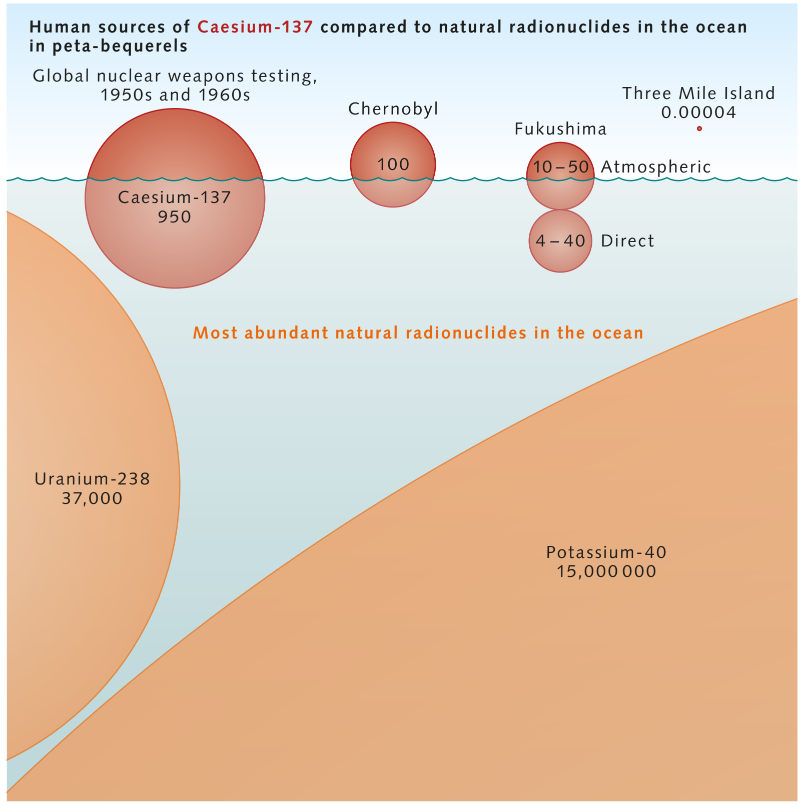
## Radioactive substances

The ocean contains many naturally occurring radioactive elements, i.e. materials made up of atoms whose nuclei are unstable (known as radionuclides). This means that they break down or change and thus release energy, in the form of various types of radiation, into the environment. Some of these radioactive elements are the result of geological processes, such as weathering of rock, or are formed when cosmic radiation reaches the Earth. They include potassium-40, a radionuclide of the chemical element potassium. Potassium-40 accounts for approximately 0.0117 per cent of naturally occurring potassium and is responsible for the weak natural radioactivity of this alkali metal.

Potassium-40 is the predominant radioactive nuclide in the sea. Due to its low-level radiation, however, it poses no threat to marine dwellers or people – unlike the radioactive substances that are released and enter the marine environment in high doses as a consequence of human activity. These radiation doses may be fatal to humans and wildlife because they damage the cells of living organisms. People



6.10 > On 25 July 1946, the USA detonated an atomic bomb at Bikini Atoll. A vast cloud of steam, water and radioactive particles erupted out of the ocean. The fleet of military vessels stationed nearby to watch the nuclear test was showered with radioactive fallout.




**6.11 > A comparison of the inventories of natural radionuclides and caesium-137 from human sources shows that the latter is present in the ocean in much smaller quantities.**

who have been exposed to high doses of radiation are also more likely to develop cancer.

A particularly high radiation risk is associated with the following scenarios:

- nuclear weapons testing and use,
- accidents in nuclear power plants,
- if radioactively contaminated cooling water or wastewater from nuclear power plants or reprocessing plants is discharged into the sea,
- if radioactive waste is dumped in the ocean,
- if there is a radiation leak from nuclear-powered vessels and submarines, or
- if radiation used in medical settings and industry enters the sea by more indirect routes.

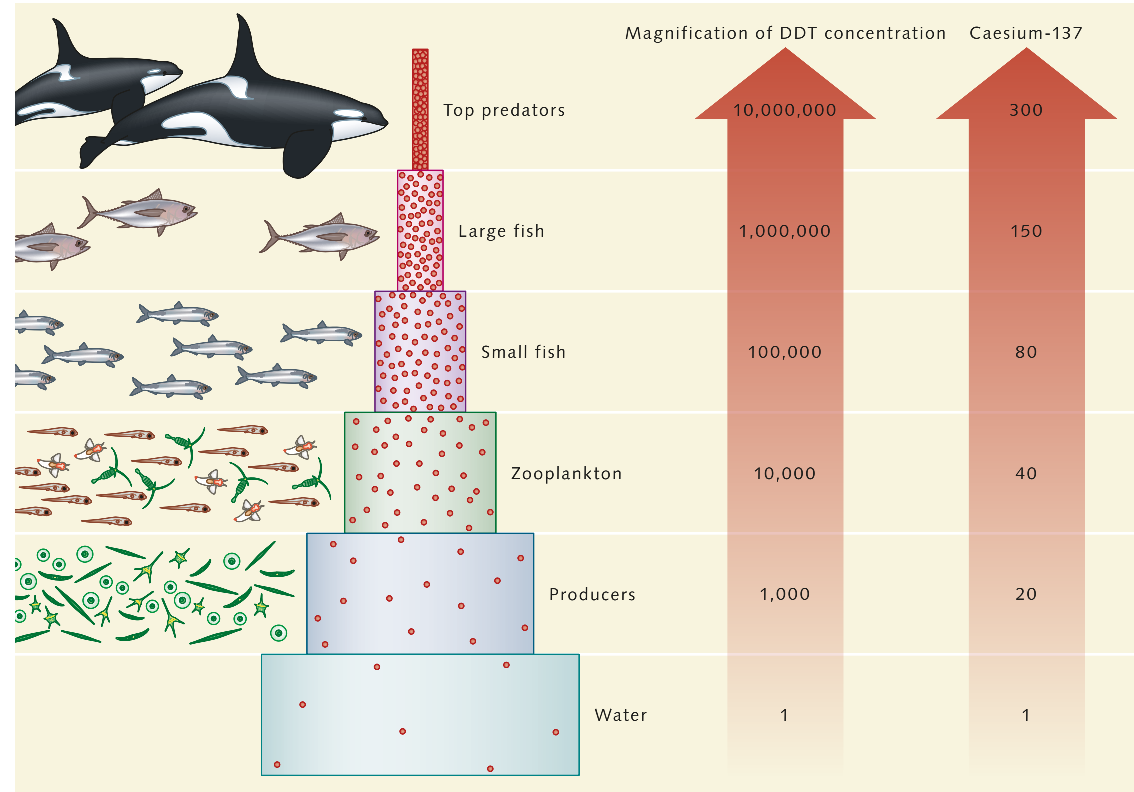
Nuclear weapons testing is the source of the largest inputs of radioactive substances in the ocean. From 1945 to 2017, more than 2000 nuclear warheads were detonated in tests worldwide. The tests were initially conducted above ground. However, as each of these blasts produced large quantities of radioactive dust, which showered down on numerous regions of the world as nuclear fallout, testing was moved underground from the 1960s onwards. Nevertheless, as a consequence of the fallout, a range of radioactive substances entered the ocean – including radionuclides which are harmful to health, such as caesium-137, strontium-90 and isotopes of plutonium and americium, as well as more innocuous substances such as tritium, carbon-14, technetium-99 and iodine-129.

Most of these substances are dissolved or diluted in water. Ocean currents and gyres thus disperse the radioactive nuclides and reduce the radiation dose. And as unstable nuclei undergo a constant process of decay, the radioactivity of these substances decreases over time, lessening the risk to health (keyword: half-life).

Nuclear weapons testing and accidents at nuclear power plants mainly release radioactive caesium-137, which is produced from nuclear fission in reactors and has a half-life of 30 years. In the aftermath of the tsunami and reactor accident at Fukushima, Japan, in March 2011, for example, caesium-137 entered the Pacific Ocean through the atmosphere (radioactive dust) and via groundwater, cooling water and firewater flowing into the sea. As a result, radiation levels off the coast of Japan near Fukushima quickly soared from just two to more than 50 million becquerels per cubic metre. For the purpose of comparison, the World Health Organization (WHO) advises against the consumption of drinking water with a radiation load above 10,000 becquerels per cubic metre.

In the sea, the masses of radioactive water were diluted and mingled with the Kuroshio Current, which flows along Japan's eastern seaboard. As a result of this process, the caesium-137 load in the coastal waters decreased significantly less than a month after most of the radioactively contaminated water entered the Pacific. At the same time, the caesium load increased at locations far from the Japanese coast. The radionuclides were transported by the main current towards North America, reaching its west coast two to four years after the reactor accident. In March






**6.12 > Unlike the insecticide DDT, harmful radionuclides such as caesium-137 have limited biomagnification in marine food webs.**

2019, researchers were still reporting raised caesium levels in the waters near Hawaii and along the Canadian and US Pacific Coast. The levels were extremely low, however – below 10 becquerels – and gave little cause for concern.

Near Fukushima itself, some of the caesium-137 adhered to particles drifting on the surface of the coastal waters and sank to the sea floor. These radioactive particles were then consumed by bottom dwellers or deposited in sediment, or were swept up and carried away by deep ocean currents, in some cases travelling distances up to 100 kilometres. Radionuclides also found their way into the deep ocean by more indirect routes – for example, in the faeces of fish, krill and other marine organisms that had ingested the particles in seawater or food.

When fish or small crustaceans ingest particles contaminated with caesium-137, the unstable atoms biodegrade surprisingly quickly. The radioactivity of caesium in fish tissue decreases by around 50 per cent within 50 days, provided that the fish leaves the contaminated area and is not exposed to further radiation. This also explains why tuna that were foraging off the coast of Japan at the time of the reactor accident and then swam away towards North America were found, just a few months later, to have a caesium load that was 15 to 30 times lower than fish species that had remained in Japanese coastal waters.

These latter waters, by contrast, were still so heavily contaminated with caesium-137 a year after the accident that radiation levels in more than half the fish specimens studied greatly exceeded the permitted maximum – probably because radioactively contaminated water continued to be discharged landside into the sea. Over time, however, the radiation load decreased, to the extent that random samples collected by Japanese fisheries inspectors in April 2015 showed no elevated levels for the first time. Thankfully, as caesium biomagnification in food webs is very limited, there was no additional risk to dolphins, sharks and other marine predators in the longer term.

**Becquerel**
The becquerel is the unit used to measure radioactivity. Named after the French physicist Antoine Henri Becquerel, it states how many nuclei decay per second. One becquerel corresponds to the amount of energy released by one single nucleus decaying.

6.13 > Off the coast of Indonesia, a seahorse clings to a cotton swab. In 2017, this photo circulated around the world and became a symbol of the pollution of the oceans by humans.



In spring 2021, TEPCO – the utility company which operates the Fukushima plant – announced plans to dump 1.24 million tonnes of radioactive cooling water and groundwater, currently stored in more than 1000 large onshore tanks, into the sea over the coming years. According to TEPCO, the water has been decontaminated, but it is unclear to what extent this decontamination process has been effective and which radioactive substances the water may still contain. For years, TEPCO had claimed that the water in the tanks contained nothing but tritium, a radioactive isotope of hydrogen which poses less of a health risk compared with other radionuclides. In October 2018, however, TEPCO was forced to concede that the water still contains other radioactive and environmentally harmful substances. TEPCO has yet to issue any clear and unequivocal statements indicating what these substances might be. This makes it difficult for experts to estimate what kind of impacts the discharge of these large volumes of water may have on the environment.

## Littering the oceans

For many people, pollution by litter is the most visible environmental problem for the oceans. Trash washed onto the beach will quickly spoil the holiday feeling. Photos and videos of turtles with plastic bags in their throats, or of seahorses clinging to cotton swabs have been shared millions of times on social networks.

Around three-quarters of the litter in the ocean comprises synthetic polymers, commonly known as plastics. This group of substances includes a number of different materials that consist of carbon-based macromolecules called polymers. More than 90 per cent of all plastics are produced from petroleum but, depending on their purpose, also contain a variety of other chemicals such as softeners, solvents and hardeners.

There are now a number of types of biodegradable plastic that are being produced and employed on industrial scales. The overwhelming proportion of plastics, however, are the conventional types that require several centuries to degrade in nature. When these conventional plastics are deposited in landfills or dumped into the environment, they do not disappear. On the contrary, they are accumulating at an alarming scale.

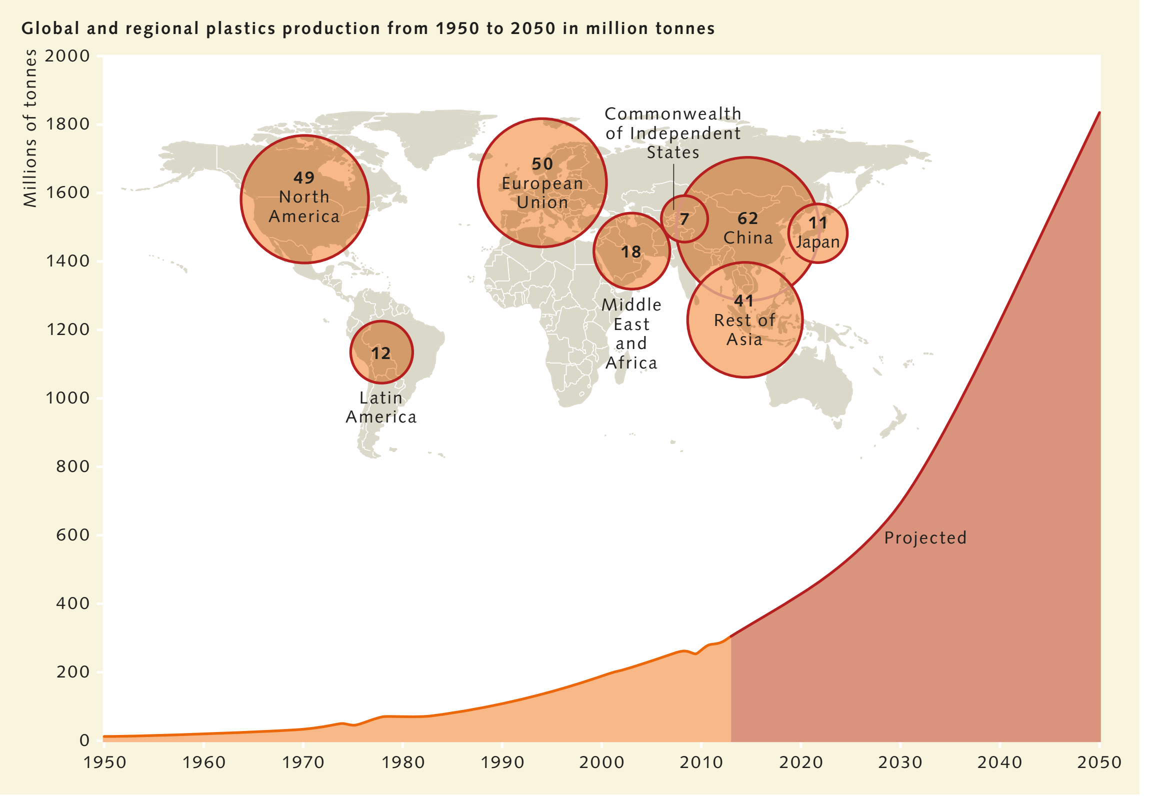
Plastics have a multitude of applications and are inexpensive to produce, which is why their worldwide production has increased so rapidly over the past 70 years. While 1.5 million tonnes of plastic were produced in 1950, this increased by a factor of 245 to some 368 million tonnes annually by 2019. In addition, more than 380 million tonnes of synthetic resins and fibres are used in textile production each year, and these are counted separately. If this trend continues, the annual production of plastics can be expected to reach two billion tonnes by 2050 and this estimate does not even include the resins and fibres.

Although now a large number of measures are in place for the recycling and reuse of plastics, especially in Europe, the greatest share of plastics is still disposed of as normal trash, in many places inappropriately, so that the amount entering the oceans is constantly growing. It is currently estimated that an additional 8.2 to 12.2 million tonnes of plastic end up in the ocean every year. This amount is equal to about three per cent of the total production. According to new research, if streams, lakes and rivers are added to the calculation, roughly eleven per cent of the plastic waste generated ends up in natural waters. In the year 2016, that was between 19 and 23 million tonnes of plastic.

What happens to the plastic in the oceans and, more importantly, the impact that this pollution has on the health of the marine organisms and of people, is only very slowly becoming understood by science. It is now generally agreed that plastic pollution in the oceans is a serious global hazard for humans and animals because creatures can become trapped in the floating waste, but also because the plastic pieces and particles are eaten or absorbed. Moreover, chemical pollutants adhere to and accumulate on these particles.

In their latest analysis, members of a UN expert group on trash and microplastics in the ocean have found that plastics not only make up the largest proportion of marine litter, but they are also the most long-lived and harmful compared to all other materials. It is estimated that the

6.14 > Enormous growth is projected for the plastics industry. In 2013 the sector produced 250 million tonnes of plastics (map). Four years later this had increased to 350 million tonnes. If this trend continues, it will be around two billion tonnes by 2050.




oceans are suffering a loss of services and functions equivalent to USD 500 to 2500 billion per year as a result of plastic pollution.

Plastics are introduced into the oceans in many different ways. The largest quantities, however, follow two major pathways:

- as clearly visible plastic waste (macroplastics) that people intentionally or unintentionally dispose of in the environment and is subsequently carried to the ocean by the wind or rivers (this includes fishing nets discarded or lost in the sea, called ghost nets);
- as microplastic particles hardly recognizable with the naked eye that are either intentionally added to commercial products (for example, cosmetic products like shower gel and toothpaste) or that are formed as unintentional by-products. The latter comprise mainly tyre-wear debris from street traffic and plastic fibres that are released when washing synthetic clothing.

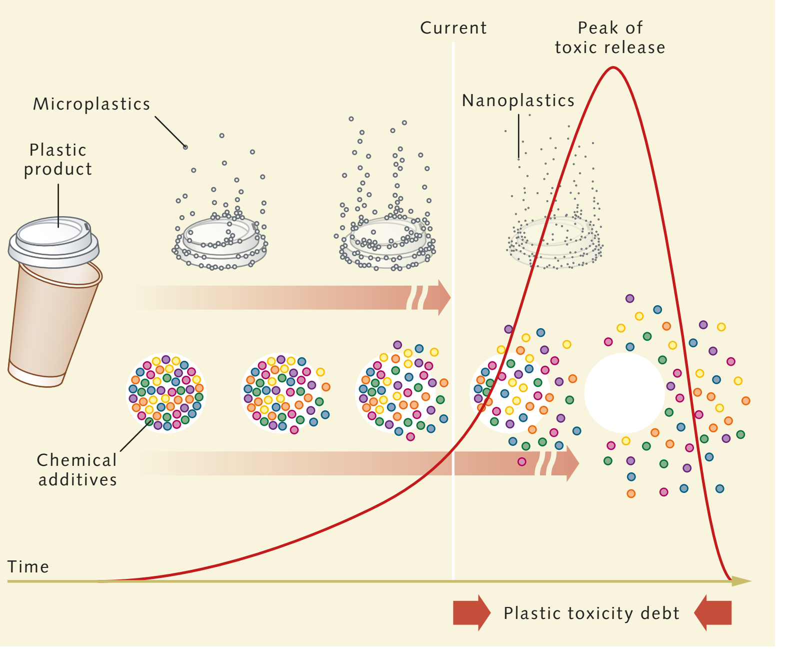
"Microplastics" are defined as plastic particles that are less than five millimetres in size. Experts distinguish between microplastics that are already micro-sized when they enter the ocean, and those that are the remains of formerly larger pieces of plastic. When they are exposed to sun and seawater, these pieces break down into progressively smaller particles, even down to nanoparticles less than one micrometre in size.

The main problem arising from this process is that as the plastic breaks down into smaller pieces, the total exposed surface area of the material increases, allowing more toxic substances and additives contained in the plastic to escape into the environment across these surfaces. Scientists are now referring to a toxicity debt that people incur when they use plastic, which means that the plastics we throw away today will generate their full toxic environmental impact only with the passing of time.

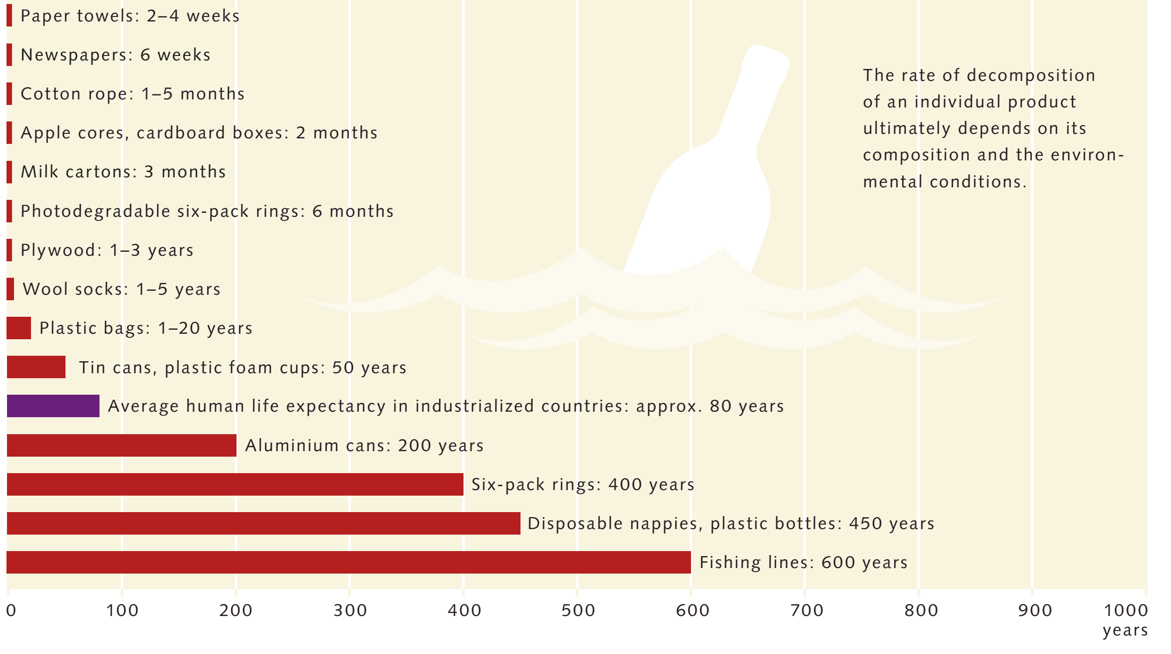
Macroplastics floating in the sea often originate directly from coastal regions, and especially from coastal states where waste management is not organized effectively. By contrast, microplastic particles may originate from regions far from the coasts. They may enter the rivers with wastewater, but can also be transported by rainwater, which washes the fine debris from tyre wear off the roads. A certain proportion of the particles is also transported through the air. Adding up the total weight of all the microplastic particles that have been introduced into the ocean, they now make up 15 per cent of the total plastics discharged into the sea.

Plastic can now be found in all ocean regions and at all water depths and is even present in the Arctic sea ice. Depending on its shape, size, density, weight and algal growth, the plastic may float on the water surface or in the water column, or it may sink to the bottom.

The ultimate destination of floating plastic litter, and whether it accumulates at a particular location, is primarily determined by the surface ocean currents and other water motions such as tides, storm floods or the flow of rivers into the sea. Computer models suggest that plastic litter in the sea is being concentrated in a number of naturally occurring gyres, especially the ocean's five large subtropical gyres. But it is a mistake to think that the litter is so densely concentrated in these regions that it can be easily recaptured. Even in those areas of the sea known as garbage patches it is mostly microplastic particles that accumulate, and those are difficult to observe with the naked eye.




6.15 > Because plastics release their additives and toxic constituents into the environment very slowly, the full damaging impacts are delayed. Scientists thus refer to a toxicity debt that we humans are incurring with the use of petroleum-based plastics.




6.16 > Much of the garbage in the ocean breaks down very gradually. Plastic products and nylon fishing lines are particularly resistant to degradation. Many of the plastic pieces do progressively break down into smaller fragments, but it can take centuries for these to completely decompose.

6.17 > A sperm whale has become entangled in a ghost net and is struggling with its last ounce of strength to reach the surface to breathe. After this photo was taken the whale dove deeper and was not seen again, despite an intensive search.

## The catastrophic consequences of marine litter

Plastic pollution of the oceans has reached dramatic proportions. It is harmful to humans as well as animals in both direct and indirect ways. Plastic-clogged estuaries and bays are breeding grounds for disease and they diminish the quality of life and earning potential in many coastal towns. Tourists avoid such unattractive places. Fishermen and -women have trouble making a profitable catch. Coastal communities in vacation regions now have to spend a lot of money to keep their beaches clean. As a consequence of plastic pollution of the world's oceans, the total costs and revenue losses recorded by global tourism, fisheries and shipping alone are at least USD 13 billion annually.

The animal and plant worlds of the oceans suffer in a variety of ways from the litter. Problems result when:

- creatures are trapped by the plastic garbage or discarded fishing nets and fishing lines and die if they are not able to free themselves;
- marine organisms mistake plastic debris for prey, eat it, and eventually die of hunger with a full stomach – or they absorb the toxic substances that are released by the plastic or that have accumulated on the plastic during its time in the sea;
- marine predators ingest plastic by consuming prey that already have plastic in their digestive systems;
- primarily smaller marine organisms attach to floating garbage, drift with it over long distances, and can end up in other locations as invasive species;
- litter or floating nets destroy marine habitats by accumulating in them;
- chemical contaminants escape from the plastics and unleash their harmful effects in the sea.

Researchers have so far identified at least 700 marine species whose lives are endangered when they come into contact with plastic garbage. Larger pieces of plastic (bags, nets, bottles, etc.) present the greatest risk for most of them. But there is now clear evidence that many marine creatures also ingest microplastic particles, including marine mammals, seabirds, fish, and some species of the zooplankton that form the base of the food web. Whether the microplastic particles also end up in the circulatory systems and ultimately in the muscle tissue of the individual animals, however, depends on their anatomy and the operation of their digestive tracts. Experiments with sea bass, for example, showed that this culinary fish excretes with its faeces almost all the microplastic particles it eats. The danger of humans ingesting plastic particles when eating filets of this kind of fish is therefore extremely low.

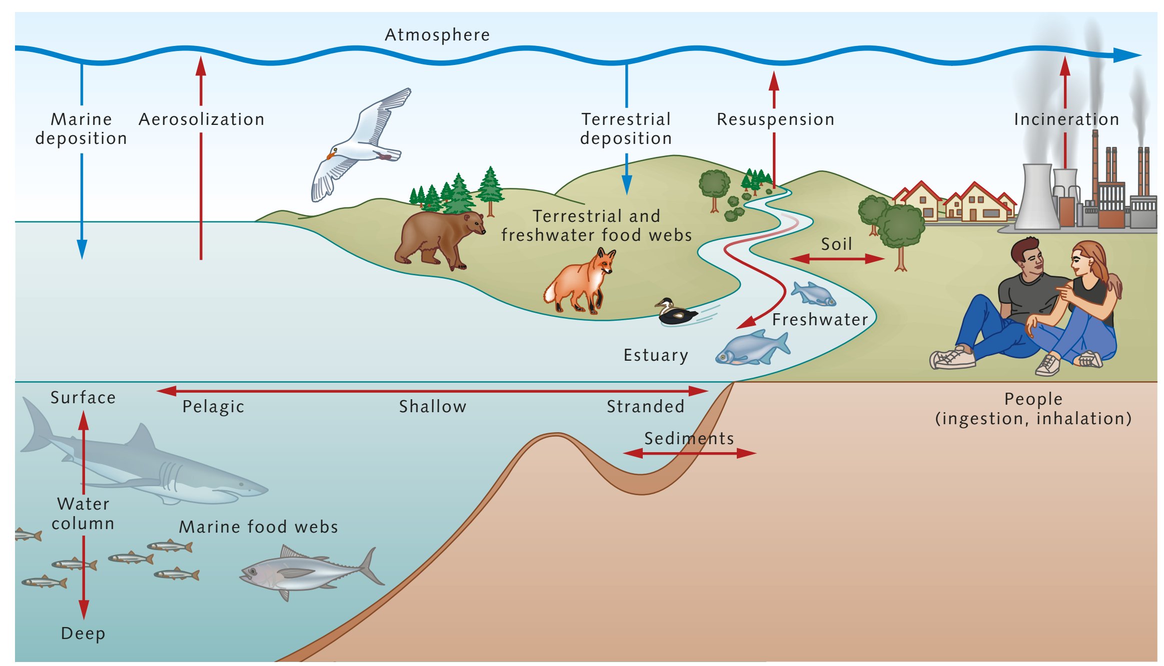
Nevertheless, there is an urgent need for action. If humans do not fundamentally change their consumption habits and attitudes with regard to plastic, it is estimated that by the year 2040 as much as 29 million tonnes of plastic garbage will find its way into the oceans each year. This amount would be equivalent to dumping 50 kilograms of plastic waste onto every metre of coastline in the world. New research shows that the ocean is no longer the final destination for microplastic particles. On the contrary, the tiny plastic particles travel in huge cycles through all levels of the Earth system and can now be detected in the air with the same confidence as in the soils and the depths of the ocean.



## A patchwork of regulations

In view of the drastic impacts of plastic pollution on land and in the ocean, solutions are now being sought at many levels. In 1995, 108 states and the European Commission became signatories to the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA), an organization for governments to discuss measures for the protection of the seas from solid waste, overfertilization and polluted effluent. In addition, in 2012, the United Nations launched the Global Partnership on Marine Litter (GPML), an international information and cooperation platform whose membership is open to representatives from politics, science, industry and civil society.

The United Nations Environment Assembly (UNEA) has so far adopted four resolutions on microplastics and litter in the ocean. In 2017 it decided to establish a UNEA expert group to study the topic. This shall identify innovative options for action at national, transregional and international levels, evaluate their feasibility and explore the factors that are still preventing the various stakeholders from effectively stemming the flood of plastics.




6.18 > Microplastic particles now migrate in a huge cycle through the individual components of the Earth system and can thus be found everywhere – in the air, in the soil, in the waters and in all food webs.

# Munitions-contaminated areas in the sea – combatting the toxic legacies of war

More than 75 years have passed since the end of the Second World War. However, there is one legacy of the war that still affects the seas and oceans and has now become a serious environmental problem. Even today, millions of tonnes of explosives and chemical weapons from the second and first world wars are still rusting away on the sea floor.

A small percentage of them are the result of actual combat operations in which marine areas were mined, or during actions in which torpedoes, aerial bombs or anti-aircraft shells sank to the sea floor unexploded. The vast majority of munitions, however, were intentionally dumped into the sea, at first by the German military who wanted to be sure during their retreat that their unused chemical weapons did not fall into the hands of the eventual victors. Later, when it was considered crucial to disarm Germany as quickly as possible at the end of the war, the allies sank shiploads of German munitions in selected dumping areas of the North and Baltic Seas.

Up until the 1960s, dumping into the sea was considered a safe and inexpensive way to dispose of munitions. For this reason, the British and US militaries also continued to discard their own outdated war materials in the sea during the post-war years. The British chose Beaufort's Dyke for this purpose, a 250-metre-deep trench between Scotland and Northern Ireland, which experts estimate now contains over a million tonnes of munitions. The Americans, on the other hand, dumped their remaining munitions in the waters off Hawaii, Nova Scotia, Newfoundland, and probably at other sites as well.

Researchers are rarely able to access these kinds of records abroad because of military security restrictions. They now know, however, that there are a great number of additional munition-contaminated marine areas around the world, including the Mediterranean and Black Seas, the west coast of the USA, the Gulf of Mexico, the east and west coasts of Australia, and around Japan. According to present knowledge, there are 1.6 million tonnes of munitions resting on the seabed in the dumping areas of the North and Baltic Seas alone.

**A global environmental problem**

Rusting munitions in the sea represent a worldwide threat for humans and marine inhabitants because they pose two kinds of danger. The first is that explosive ordnance can still detonate, for example, when mines are disturbed by bottom-fishing nets or when construction work for wind farms is initiated without prior examination of the sea floor for old munitions.

The explosion of a sea mine would trigger a shock wave that would kill all of the marine creatures in the close vicinity and shred the blood vessels and alveoli of whales, seals and other marine mammals over a greater distance. Divers and ships' crews would also be exposed to extreme danger, which is why the seabed has to be examined for explosive munitions prior to any construction being carried out in German waters. If munitions are found that can be moved, they are raised and placed on board a ship, transported to land and destroyed there. If lifting the ordnance safely is not possible, the munitions are carefully placed in a hoisting bag and towed to one of the dumping areas in the Baltic Sea where construction work is prohibited. In this case, permanent destruction is not an option, because there is currently no known procedure for neutralizing explosive ordnance in the sea in an environmentally acceptable way. In the North Sea, however, highly explosive munitions are sometimes towed to sandbanks that are above water at low tide. During low-water stands they can then be detonated without causing great harm in the sea.

The second danger to the environment is chemical in nature. Both explosive and chemical weapons contain various components that are increasingly leaking into the water due to the ongoing decay of the metal munition coverings, eventually dissolving in the water, and being distributed throughout the ocean by marine currents. Trinitrotoluene (TNT), the substance contained in explosives, for example, breaks down into as many as 50 different reaction products known as metabolites. The two most commonly occurring TNT metabolites, like their parent material, have been proven to cause cancer and have already been detected in mussels and the organs of fish in dumping areas of the Baltic Sea. The meat of the fish, however, was not significantly contaminated.

In 2018, when researchers from Kiel studied water samples taken from various regions of the German Baltic Sea, they found traces of TNT or its metabolites in every one of the approximately 1000 samples, because the substance first begins to metabolise in the sea and the process toward complete degradation proceeds very slowly. The long-term effects that the compounds used in explosives are having on biological communities of the North and Baltic Seas, and the concentrations at which they will cause demonstrable damage are now being studied by the researchers in various projects. So far, they have only been able to record notably high concentrations of TNT in the waters directly in the dumping areas.

Chemical munitions were dumped in barrels as well as in the form of bombs and grenades. Most of them contained nerve gases like tabun and phosgene, or the skin-damaging mustard gas. Tabun and phosgene degrade relatively rapidly in sea water. As a liquid, however, mustard gas goes through a process known as the coconut effect. It forms a hard crust and is encapsulated inside. If an angler happens to find one of these nuts and comes into contact with the liquid core, the carcinogenic chemical will still cause the same severe skin burns today that it did more than 100 years ago.

**Time is pressing – possible solutions from science**

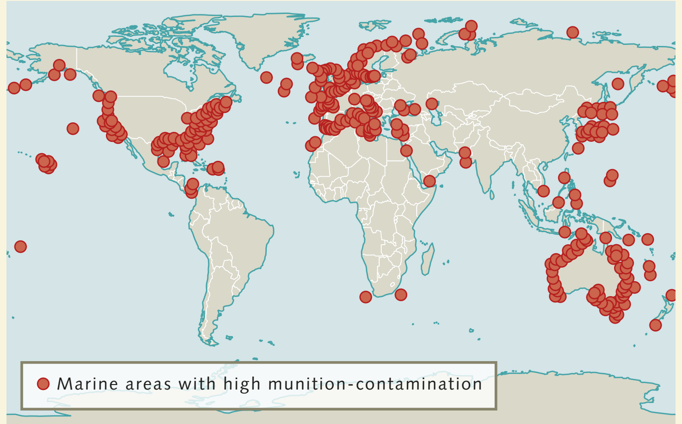
The longer the munitions lie in the sea, the further their casings continue to rust. They are thus becoming increasingly difficult to handle, and more and more of their contents are dissolving in the water. Because of this growing environmental threat, scientists are calling for the creation of long-term monitoring programmes for the piles of munitions in the dumping areas. These include:

- a scientific evaluation of historical records of combat operations and munition dumping (Where might munitions be located?);
- comprehensive mapping of the known munitions-contaminated areas (What quantities of known munitions are lying on the sea floor?);
- regular monitoring of the chemical contamination of the sea and its biological communities (What chemicals are being released and in what quantities?);
- accompanying studies on the effects of storms, marine currents, temperature, salinity and oxygen content on the munitions (mechanical attrition processes, shell degradation, displacement, covering by sediments, etc.);
- development of new methods for safe disposal of the weapons.

In recent years, the researchers have employed and refined a number of methods for mapping the sea floor. Through a combination of photography, multibeam echosounding and magnetic mapping, scientists can now produce impressively high-resolution images of the seabed in which mines, weapons boxes or torpedoes can be easily distinguished from rocks or other natural objects. Similar progress is being made in the development of rapid analysis methods. With the help of mobile mass spectrometers, scientists can now detect TNT and other compounds typical of explosives.

In the next step, German experts, along with many partners, want to develop technical methods for the safe and ecologically responsible clean-up of the munitions-contaminated areas directly at sea. The idea is to raise the munitions and load them onto a pontoon. Robots there would cut open the shells and remove all the chemical contents. The metal remains could be recycled and the chemicals would be thermally treated. The scientists want to have an initial prototype of this kind of system built and tested by the year 2025.

Scientists will soon make all the relevant data from international research on old munitions in the sea available online in a map-based information portal named AmuCad.org. The system uses artificial intelligence and other data-analysis approaches to identify regions with particularly high potential for risk. Using a colour-coded traffic-light system, decision-makers will be able to better identify marine areas where munitions are decaying especially rapidly, as well as zones with large quantities of munitions that are being used more intensively by humans. In both cases, it would be advisable to establish monitoring programmes and make plans for the removal of explosive ordnance.




**6.19 > Ocean scrap yards in the form of dumped munitions are a global problem. Particularly former combatants such as the USA, Japan, Great Britain and Australia have dumped old stockpiles into the ocean and are now having to deal with the consequences.**

Furthermore, the governments of the 20 largest industrialized nations agreed in 2019 to reduce the input of new plastic waste into the oceans to zero by the year 2050. This plan is to be achieved by the introduction of a circular economy for carbon-based plastics, improved waste management, and the development of new, more environmentally friendly materials. With this commitment, the industrialized nations are also retreating from the decades-long political strategy of viewing plastic pollution of the environment as a purely consumer problem and completely ignoring the true cause, which is the production and diverse application of long-lasting plastics.

At the transregional level, regulations on how to deal with terrestrial sources of waste have been stipulated in a number of regional marine conservation agreements, for example, in the Caribbean (Cartagena Convention), in the Mediterranean (Barcelona Convention), in western Africa (Abidjan Convention) and in the western Indian Ocean (Nairobi Convention). Those covering the Baltic Sea region (HELCOM Convention), the Northeast Atlantic (OSPAR Convention) and the seas of East Asia have even been able to agree on concrete plans for preventing or combatting the waste input to their respective waters. Ten regional marine agreements, furthermore, prohibit ship and platform crews from disposing of garbage in the sea, thus complying with an international ban prescribed by the MARPOL Convention, the international agreement to prevent marine pollution by ships. Experts, however, raise the concern that regional marine initiatives often lack the necessary money, human resources and contacts with local business communities that would be needed to fully and effectively implement their own regulations and decisions.

At the national level, countries are increasingly taking measures to reduce or completely prevent environmental pollution by plastics. Many of these measures aim to prohibit the use of disposable plastic products like bags or dishes, either through a ban on sales or by high taxes on the products. However, the outbreak of the corona pandemic at the beginning of 2020 has brought many of these efforts to a halt. Due to the fear of infection more food products worldwide are again being packed in plastic, drinks sold only in disposable cups, and generally more disposable dishes are being distributed.

6.20 > An eleven-year-old girl collects plastic waste from Jakarta's huge tip. Exposed mountains of trash like this generate a multitude of environmental problems. Methane escapes into the atmosphere and toxic water leaches into the ground. In addition, the wind blows away everything that is not heavy enough to remain in place.

There are many other basic questions that still need to be answered. One of the greatest challenges is to establish functioning waste management systems worldwide. In many countries there are still too few households connected to local waste-disposal systems. Without these services, discarded plastic products can neither be collected nor recycled. Researchers have made projections regarding this problem. In order to properly dispose of all plastic waste generated in the private sector by 2040, more than one million households would have to be added to waste collection systems every week, and this would have had to begin in the year 2020. This would be a huge task requiring enormous investments.

Experts also see an urgent need for:

- improvements in scientific monitoring systems for waste pollution, in order to learn where and over what pathways the garbage enters the environment;
- development of environmentally friendly alternatives for all non-biologically degradable types of plastics;
- producers to take responsibility that the products they manufacture are recycled and their components reintroduced to the circular economy;
- fundamental transformation of our economic system, so that it can fulfil the criteria for sustainable development. The prerequisite for this, however, would be for every individual consumer to fundamentally change their consumption patterns.

Parallel to these developments at the political level, there are now a number of initiatives by businesses and civil society. These include:

*Worldwide litter collection actions on beaches and river banks*

One of the best-known initiatives is International Coastal Cleanup Day, an event that the US environmental organization Ocean Conservancy has been holding each September for more than 30 years. In 2019 these marine conservationists and their partner organizations around the world cleaned almost 40,000 kilometres of coastline and collected 9.4 million kilograms of garbage, most of which was food packaging, cigarette butts, plastic bottles and plastic straws.

*Developing new technologies for waste collection and disposal*

Many small start-up companies are now developing a variety of new methods for removing plastics from the sea and, in the best-case scenarios, to profitably reprocess them. The spectrum of possible solutions ranges from giant plastic barriers that capture trash floating on the sea surface, to garbage-collection boats with large conveyor belts, water-filtering systems, and trash robots that patrol harbour basins collecting floating materials.

*Initiatives to expand the circular economy*

Industry and business are also now becoming more involved. For example, more than 500 businesses and organizations have joined the New Plastics Economy Global Commitment, a worldwide initiative of the Ellen MacArthur Foundation and the United Nations Environment Programme. The signatories plan to work together to significantly reduce the amount of plastic in the packaging industry, avoid unnecessary packaging and work specifically toward a closed circular economy so that plastic used for packaging purposes never has to be disposed of as waste.

In their annual report for 2020, the initiators write that the greatest progress has been achieved in the re-use of recycled plastic within the packaging industry. However, many of the plastics used are still not sufficiently recyclable. Moreover, the number of disposable plastic articles sold around the world is still much too high.

For this reason, scientists and a number of governments are also calling for an international agreement to reduce the plastic pollution of the planet, with clear joint objectives and binding commitments from all nations. The European Commission and other high-level political institutions support this initiative. At the international level, preliminary talks on how such an agreement should look have been underway since 2019. Critics respond that the lengthy negotiations for such an agreement are actually harmful to the struggle against plastic waste, because they prevent many stakeholders from taking immediate effective measures in the real world.

The United Nations Environment Assembly therefore advocates a dual approach. While their expert committee studies whether an international agreement would be effective and what guidelines it would have to include, the political, business and civil branches should continue to concentrate on implementing existing national regulations, establishing a circular economy, raising awareness within the general population and expanding research in the field of plastic in the oceans. There are actually two major aspects to be considered. Firstly, there is not a single correct solution for humanity's plastic problem; a variety of measures will be required. Secondly, time is pressing. As long as we humans continue to act as we have in the past, plastic pollution in the ocean will increase dramatically, with severe consequences for the health of all inhabitants of the ocean and all those who profit from it.

**6.21 > The international community is attempting to regulate the way chemicals and waste are handled worldwide through a series of legally binding agreements. The following table lists the most important agreements, briefly describes their objectives, and gives the number of substances addressed and number of signatory states.**

**Multilateral agreements related to the sound management of chemicals and waste**

| Agreement | Adoption and entry into force | Goals | Number of chemical substances addressed | Number of Parties as of 14 January 2019 |
|---|---|---|---|---|
| Montreal Protocol on Substances that Deplete the Ozone Layer | • Adopted at the Conference of Plenipotentiaries on the Protocol on Chlorofluorocarbons to the Vienna Convention for the Protection of the Ozone Layer in Montreal in 1987<br>• Entered into force in 1989 | • Protect human health and the environment against adverse effects resulting, or likely to result, from human activities which modify or are likely to modify the ozone layer;<br>• Protect the ozone layer by taking precautionary measures to control equitably the total global production and consumption of substances that deplete it, with the ultimate objective of their elimination on the basis of scientific knowledge, technical and economic considerations, and the developmental needs of developing countries. | 144 | 197 |
| Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal | • Adopted at the Conference of Plenipotentiaries in Basel in 1989<br>• Entered into force in 1992 | • Effective implementation of Parties' obligations with respect to transboundary movements of hazardous and other wastes;<br>• Strengthening the environmentally sound management of hazardous and other wastes;<br>• Promoting the implementation of environmentally sound management of hazardous and other wastes as an essential contribution to the attainment of sustainable livelihood, the 2000 Millennium Development Goals, and the protection of human health and the environment. | 124 groups of wastes, according to Annex I, II and VIII List A, and wastes falling under the criteria of the list of hazardous characteristics in Annex III | 187 |
| ILO Chemicals Convention C170 | • Adopted at the 77th Session of the International Labour Conference in Geneva in 1990<br>• Entered into force in 1993 | • Reduce the incidence of chemically induced illnesses and injuries at work by ensuring that all chemicals are evaluated to determine their hazards;<br>• Provide employers with a mechanism to obtain information from suppliers about the chemicals used at work;<br>• Provide workers with information about the chemicals at their workplaces, and about appropriate preventive measures so that they can effectively participate in protective programmes;<br>• Establish principles for such programmes to ensure that chemicals are used safely. | Not applicable | 21 |
| Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction | • Adopted at the 635th plenary meeting of the Conference on Disarmament in Geneva in 1992<br>• Entered into force in 1997 | • Achieve effective progress towards general and complete disarmament under strict and effective international control, including the prohibition and elimination of all types of weapons of mass destruction;<br>• Exclude completely the possibility of the use of chemical weapons, including prohibition of the use of herbicides as a method of warfare;<br>• Promote free trade in chemicals, as well as international cooperation and exchange of scientific and technical information in the field of chemical activities for purposes not prohibited under the Convention;<br>• Completely and effectively prohibit the development, production, acquisition, stockpiling, retention, transfer and use of chemical weapons, and their destruction. | 15 toxic chemicals and 28 precursors | 193 |
| ILO Convention concerning the Prevention of Major Industrial Accidents C174 | • Adopted at the 80th Session of the International Labour Conference in Geneva in 1993<br>• Entered into force in 1997 | Having regard to the need to ensure that all appropriate measures are taken to:<br>• Prevent major accidents;<br>• Minimize the risks of major accidents;<br>• Minimize the effects of major accidents. | Not applicable | 18 |

**Multilateral agreements related to the sound management of chemicals and waste**

| Agreement | Adoption and entry into force | Goals | Number of chemical substances addressed | Number of Parties as of 14 January 2019 |
|---|---|---|---|---|
| Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade | • Adopted at the Conference of Plenipotentiaries on the Convention in Rotterdam in 1998<br>• Entered into force in 2004 | • Promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals, in order to protect human health and the environment from potential harm and to contribute to their environmentally sound use, by facilitating information exchange about their characteristics, by providing for a national decisionmaking process on their import and export and by disseminating these decisions to Parties. | 50 substances and mercury compounds | 161 |
| Stockholm Convention on Persistent Organic Pollutants | • Adopted at the Conference of Plenipotentiaries on the Stockholm Convention on Persistent Organic Pollutants in Stockholm in 2001<br>• Entered into force in 2004 | • Protect human health and the environment from Persistent Organic Pollutants (POPs);<br>• Eliminate or restrict the production, use, import and export of listed POPs, and require measures to be taken with respect to waste and unintentional releases of POPs. | 28 POPs and mentioned salts | 182 |
| WHO International Health Regulations (IHR) (2005) | • Adopted by the 58th World Health Assembly in Geneva in 2005<br>• Entered into force in 2007 | • Prevent, protect against, control and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks, and which avoid unnecessary interference with international traffic and trade (Article 2). | Not applicable | 196 |
| Minamata Convention on Mercury | • Adopted on the occasion of the Conference of Plenipotentiaries on the Minamata Convention on Mercury in 2013<br>• Entered into force in 2017 | • Protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds.<br><br>Commitments by Parties include:<br>• Ban new mercury mines and phase out existing ones;<br>• Phase out and phase down mercury use in a number of products and processes;<br>• Establish control measures for emissions to air and releases to land and water;<br>• Environmentally sound interim storage of mercury, and its disposal once it becomes waste. | Mercury and mercury compounds | 101 |

## Conclusion

### Seas brimming with litter and pollutants

Not only does the world ocean play a major role in the climate and species-diversity crises of the Earth. It is also affected by a third global environmental crisis: the widespread pollution of terrestrial and marine areas. Every year as much as 400 million tonnes of pollutants end up in lakes and rivers, and ultimately in the seas. These include thousands of different chemicals, nutrients, plastics and other synthetic products, toxic heavy metals, pharmaceuticals, cosmetic products, pathogens, radioactive substances and much more.

In eight of ten cases, pollutants identified in the sea originate from terrestrial sources. As industrial or household waste, they are either discharged directly into the water, escape from poorly functioning wastewater treatment plants, are washed from the fields and streets by rainfall from above, or are leached from landfills and garbage dumps into subterranean water channels or streams. Litter and plastics are also carried to the sea by the wind. The remaining input of pollution occurs directly at sea, as a result of fishing and aquaculture or from shipping.

Winds and ocean currents transport garbage and pollutants to the most inaccessible regions of the world's oceans. Evidence of the pollution can be found on remote islands, in the polar sea ice and in deep ocean trenches. Pollutants especially hazardous for marine biotic communities are those that are long-lived and that accumulate in the food webs. These are characteristic, for example, of the group of persistent organic pollutants (POPs), which includes many pesticides and industrial chemicals.

The consequences of contamination are manifold and are distinguished according to the species affected and pollutant concerned. Known environmental pollutants cause diseases such as cancer, evoke deformities and behavioural changes in marine organisms, impair reproduction in affected species and can cause death in contaminated individuals. As a rule, predators at the highest trophic levels are especially impacted by environmental pollutants. These include sharks, toothed whales and seals. Animals that come into contact with plastic waste are in danger of being trapped, or of ingesting the plastic and starving with a full stomach. At least 700 animal species have now been identified for which plastic in the ocean can be a deadly hazard.

The international community is attempting to limit the input of pollutants into the seas through a variety of international agreements as well as transregional and national regulations. The prohibition of selected persistent organic pollutants by the Stockholm Convention, for example, is delivering results. The concentrations of these pollutants in the sea are declining.

But in many other cases, politicians and scientists are facing the problem that regulatory authorities are not always fully informed about the chemicals that are used in popular products, or about the impacts these ingredients would have should they someday end up in the sea. In many cases, the risk analyses required for a ban on dangerous substances are only possible after excessive quantities of them have already been introduced into the ocean and researchers are able to demonstrate the links between pollutant input and ecosystem destruction.

An end to the crisis of marine pollution will not be possible until a large proportion of the households and businesses around the world are connected to functioning sewage and solid-waste management systems, until substances toxic to the environment and carbon-based plastics are replaced by biodegradable alternatives, and the use of chemicals and plastics is limited to closed-loop systems.